ELECTROKINETIC STABILIZATION OF KAOLINITE SLOPE

By

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Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2005

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted for this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been taken or done by unspecified sources or persons.

MOHD KHAIRULNIZAM BIN YOB

ABSTRACT

This report assists the remedy selection process by providing the best methodology in conducting the electrokinetic method in term of stabilizing kaolinite slope. The reports also discuss the objectives of this research and the way how to run the testing or experiment from the model which is specially design for testing purposes.The objectives of this study are to determine the effectiveness of the electrokinetic method for the purpose of soil treatment. Some of experiments were conducted on the kaolinite soil such as sieve analysis, Compression test for soil strength and vane shear test. All those testing were intended to establish the properties of the kaolinite soil. The experimental work was done using the model which specially fabricated. The dimension of the model work is 9" X 16" in the box shapes consist the slope of kaolin. Several set of laboratory testing have been done to ensure that the soil properties was the same with a real kaolin properties and to ensure it is suitable to use in test. Three factors were considered in this testing which is moisture content, shear strength and the current flow in the soil. From the result obtained, it was found that electrokinetic method was shown some improvement in the desired factors. Overall, the study on Electrokinetic Stabilization of kaolinite slope was observed to be effective as the method capable on increased the strength of the slope. From the analysis, it also found that the effectiveness of the electrokinetic method depends on the voltage, period of testing and also the arrangement of the cathodes and anodes along the slope. However, the thorough study and research should be made for more findings in the future.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Electroosmosis is a well known technique in soil stabilization method. It is but one of the phenomena that arise in soils after the application of Direct Current (DC) electric field. After an overview of coupled transport phenomena as provided by the theory of irreversible thermodynamics, a microscopic scale insight to electrical field related transport mechanisms will be furnished. Those notions are necessary in order to understand critically the models available for electrokinetic remediation.

The evolution of slope stability analyses in geotechnical engineering has followed closely the developments in soil and rock mechanics as w whole. Slopes either occur naturally or are engineered by humans. Slope stability problems have been faced throughout history when men and women or nature has disrupted the delicate balance of natural slopes. This research encompasses general slope stability concepts and soil stabilization methods [1].

This study shall focus on slope stability by using electrokinetic method, as one of the stability treatment process. It involves the experimental studies using the equipments which have been set up and observing the phenomena of the slope using those equipments in the geotechnical laboratory. The experiment was conducted by using the special equipments designed to run the testing throughout the research.

1.2 Problem Statement

1. Study on slope stability problem in Malaysia is required as a reference for soils treatment process in stabilize the slope. Further, electrokinetic has been reported to be a good method in soil stabilization in removing the contaminants from the soil but there were very little application of stabilizing the slope using electrokinetic method. [1]

As electrokinetic is concerns, the type of the electrodes also may affect the effectiveness of this method. The general layout of the electrodes depends upon purposes. Sheet piles of any shape can be used. The simplest types of anode for normal application are old pipes which can be driven easily into soil. Therefore, this study also required to determine the arrangements of anodes and cathodes applicable in service especially in construction industries.

1.3 Objectives

The main objectives of the project are:

1.3.1 To determine the effectiveness of the electrokinetic method on stabilizing kaolinite slope.

1.3.2 To study the effect of electrical current on kaolinite slope

1.3.3 To look at the effect of different arrangement of the electrodes along the slope.

1.3.4 To study the possibility of reducing sufficient pore water pressure and moisture content using electrokinetic in kaolinite slope without using any surcharges.

The scope of the study will be limited to:

1.3.5 Basic laboratory tests on kaolinite (White China Clay) soils in order to determine its properties.

1.3.6 Conducting literature review on electrokinesis application in soil stabilization for slope purposes.

1.3.7 Fabricating the equipment to run the testing of the slopes. The model will represent the actual slopes and some testing will be conducted by using the electrokinetic and non-electrokinetic method. The voltage applied to the sample is limited to 10 volt, 20 volt and 30 volt only.

1.3.8 Analysis of the results obtained by comparison between the behavior of the soil slope sample before and after the treatment process.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Electrokinesis

Electrokinesis remediation relies on the application of low intensity direct current between electrodes place in the soil. The application of this method on slope stability is very rare among the researcher. The slopes may suddenly fail because of changes in topography, groundwater flows, loss of strength and other causes. This has been emphasized by Peck (1967), who said:

Our chances for prediction of the stability pf the slope are perhaps best if the area under study is an old slide zone which has been studied previously and may be reactivated by some human operations such as excavating in the toe of the slope. On the other hand, our chances are perhaps worst if the mechanism triggering the landslide is at a random not previously studied location. [1]

When a direct voltage is applied across a soil, electrokinetic transport processes (electrophoresis, electromigration and electroosmosis) occur. Electrokinetic techniques can effectively extract a variety of inorganics and contaminants and radionuclides from soils, especially those with low permeability.

Electrokinetic phenomena in porous medium are basically based on the relative motion between charged surface and the bulk solution at its interface. The formation of an electric double layer at the charged surfaceof clay particles is responsible for electrokinetic phenomena of interest, namely *electroosmosis, electrophoresis* and *electromigration.*

One of the key redox processes is the water electrolysis:

Anode: $H_2O \Rightarrow \frac{1}{2} O_2 \uparrow + 2H^+ + 2e^-$

Cathode: $2H_2O + 2e^- \Rightarrow H_2 \uparrow + 2OH^-$

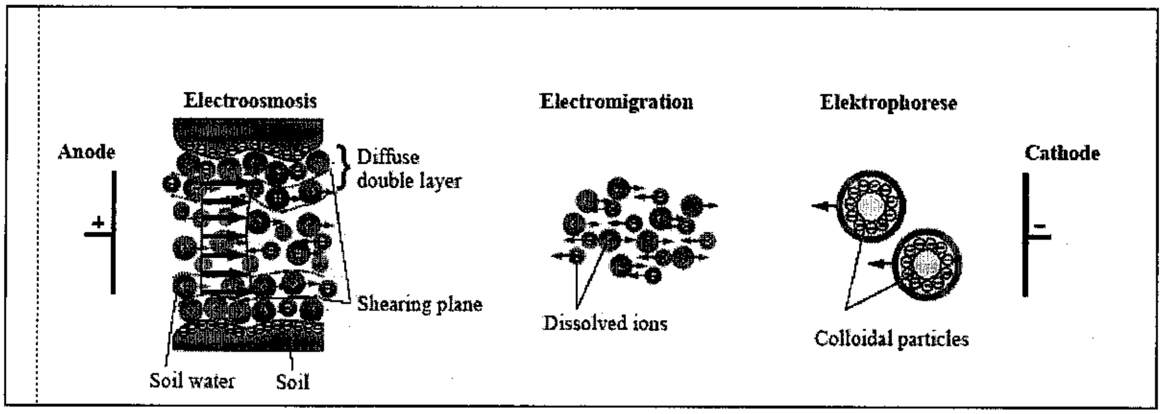

Figure 2.1 Electrokinetic transport processes in a DC electric field

2.1.1 Electrophoresis

Electrophoresis is defined as the migration of charged colloid, not small ions, in solid-liquid mixture under electric potential gradient, where discrete particles are transported through water. If a direct current (DC) is applied to clay-water systems, negatively charged clay particles will migrate toward the anode. In a compact system of porous plug, electrophoresis is of less importance due to restrained solid phase.

2.1.2 Electromigration

Electromigration is defined as the movement of charged ions towards the oppositely charged electrodes relative to solution. In a dilute system or a porous medium with moderately concentrated aqueous solution of electrolytes, electromigration of ions is the major cause of current conduction. With regard to contaminated soils, electromigration is the primary mechanism of electroremediation when the contaminants are ionic or surface charged.

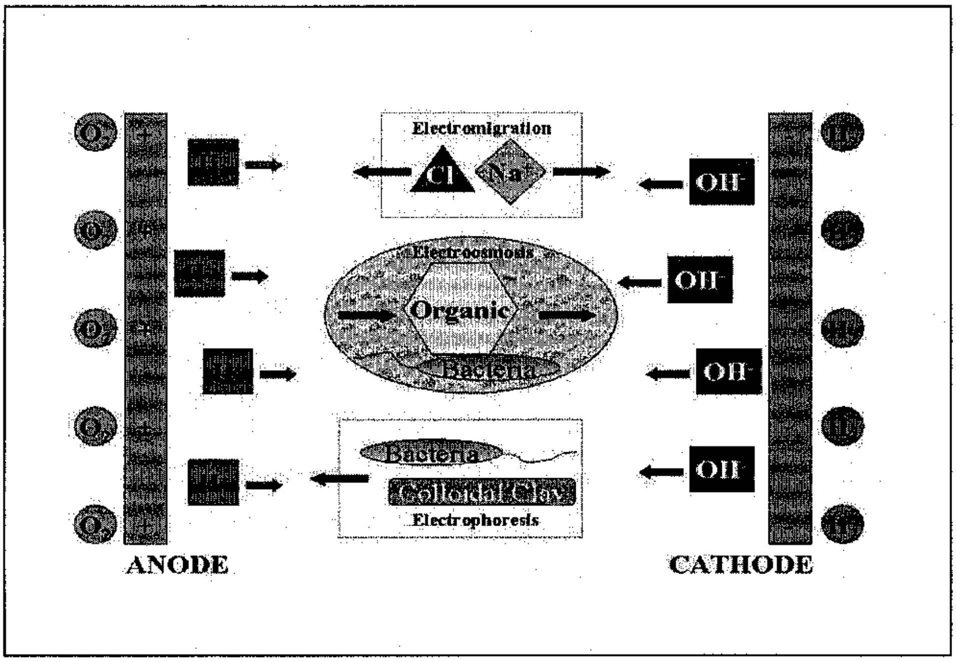

Figure 2.2 The Transport Process of Ions

2.1.3 Electroosmosis

Electroosmosis involves water transport through continuous soil particles network, where the movement is primarily generated in the diffuse double layer or soil moisture film. The principle mechanism electroosmosis is the migrating ions, where the cations migrate to the cathode and the anions move toward the anode. Accordingly, when an electric field (DC) is applied to clay-water system, the surface or particle is fixed, whereas the mobile diffuse layer moves carrying solution with it.

Elctroosmosis flow is shown to be independent to the pore size distribution or the presence of macropores. Hence, the ability of electroosmosis to produce a rapid flow of water in a compact low permeability soil makes it significant to soil decontamination process by advection (Mitchell, 1993). It is also learnt that the relative contribution of electroosmosis and ion migration to the total mass transport varies according to soil type, water content, types of ion species , pore fluid concentration of ions and processing conditions.

Gray and Mitchell (1967) showed experimentally that although the electroosmosis flow increases with increasing water content of most soils, the flow decreases with increasing electrolyte concentration of the pore fluid. In addition, they observed that the fundamental importance in electroosmosis phenomena is the cation-anion distribution and the water-ion distribution in the soil. They stressed that in clays and other ion exchangers, the positive counter-ions required to balance the negative fixed charges on the solid particles are in the majority and hence they impart more momentum to the water than do the co-ions (co-ions are ions with the same signs as the fixed surface charges on a clay or other exchangers). So there is a net water transfer in the direction of counter- ion movement.

The electroosmotic flow rate resulting from the movement of solvated ions concentrated outside the stationery layer when a packed bed of clay particle is saturated with an electrolyte and exposed to voltage gradient is described by the Helmholtz-Smoluchowski's equation in which

$$q_{co} = \left[\frac{-\zeta D\, n}{\eta}\right]\left[\frac{\Delta E}{\Delta L}\right] A \qquad (1)$$

where ζ= zeta potential, D= dielectric constant of the pore fluid, η= viscosity of pore fluid, n = porosity, ΔE = potential difference, ΔL = length of soil sample, and A = cross-sectional area of sample.

Based on eq. (1), a negative zeta potential results in a positive flow rate, indicating flow toward the cathode and vice versa. This equation can be related to Darcy's law and written as

$$q_e = k_e\, I_e\, A$$

where k_e = eletroosmotic permeability, i_e = voltage gradient, and A = cross-sectional area.

The similarity between Eq. (1) and Eq. (2) can be observed, where the terms in the first and second parentheses of Eq. (1) are equivalent to k_e and i_e in Eq. (2), respectively.

Conventionally, electroosmotic flow in clayey soils take place from the anode toward the cathode as most soil particle surfaces are negatively charged as a result of isomorphous substitution and the presence of broken bonds. In order to balance the charge deficit, the mobile ions in the pore fluid have to be positively charged. In most clays, the range values of zeta potential is between 0 and -50 mV, depending on the chemistry of the sol system (Yeung et al., 1997).

In addition to the water transport between the electrodes, oxidation and reduction take place at the electrodes as electrons are transferred in and out the system (Gray and Mitchell, 1967; Thomas and Lentz, 1990; and Mitchell, 1993), resulting in ion diffusion, ion exchange, development of osmotic and pH gradients, dessication by heat generation at the electrodes, mineral decomposition, precipitation of salts or secondary minerals, electrolysis, hydrolysis, oxidation, reduction, physical and chemical adsorption, and fabric changes (Mitchell, 1993). Some of the changes may be beneficial while the others may retard the efficiency of electroosmosis. Electrolysis of water at anode and the cathode produces oxygen and hydrogen respectively, which can be represented by the following equations;

$$2H_2O - 4e^- \rightarrow 4H^+ + O_2\uparrow \qquad \text{(anode)} \qquad (3)$$

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2\uparrow \qquad \text{(cathode)} \qquad (4)$$

Based on Eq. (3) and Eq. (4), it is noteworthy that both H^+ and OH^- sweep across the soil sample toward the cathode and the anode, respectively during the course of electrokinetic processing. Since H^+ travels approximately two times faster than OH^-, prolonged electrokinetic processing will result in acidification of the treated soil.

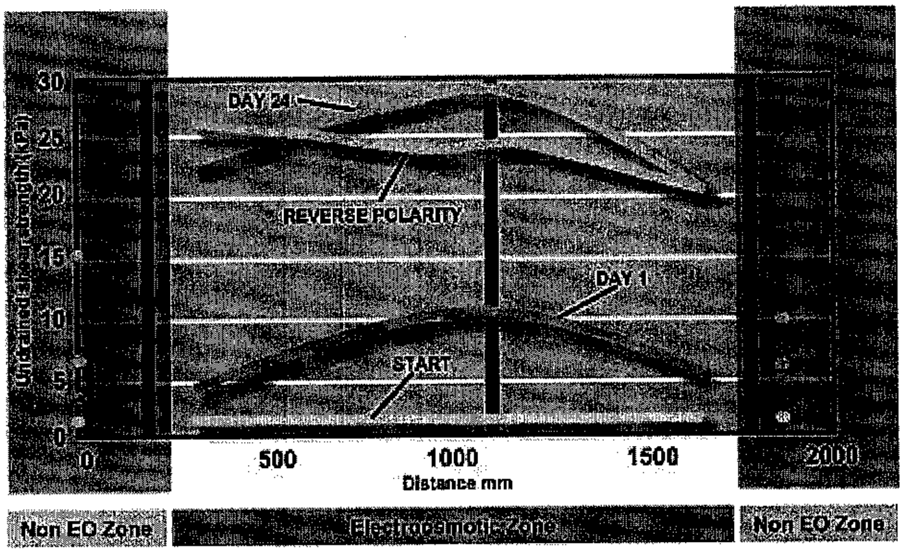

Figure 2.3 The Consolidation Behavior of Soil

2.2 Effect of Electroosmosis on a Natural Soil, Field Test

A unique configuration of horizontal sheet like electrodes was used in the field at a site in Ohio underlain by silty clay glacial drift in order to induce electroosmotic flow and to characterize the effect of electroosmosis on soil properties for example pH and electrical conductivity. The lower electrodes was created by filling a flat-lying hydraulic fracture with graphite and the upper one is metallic mesh placed on the ground surface and covered with the sand. The electrodes were attached to a DC power supply, creating an electrical gradient of 20 to 31 V/m with a current of 42 to 57 A through approximately $20m^3$ of soil. Total energy applied was 5500 kW-h during approximate 4 months of operation. Electroosmotic flow rates of 0.6 to 0.8 l/hr were observed during test lasting for several weeks although the total flow rate (electroosmotic plus hydraulic) was strongly influenced by fluctuations of the groundwater table. The ratio of applied current voltage decreased from 0.9 to 0.6 A/V and was mainly due to a decrease in electrical conductivity of the soil. A front of low pH developed at the anode and migrated to the cathode. The velocity of the pH front per unit voltage gradient was $0.014^{cm/day}/_{V/m}$. This is 40 times slower than what has been reported from laboratory experiment using kaolinite as a medium. These result confirm the feasibility of using this new electrode design at shallow depths, but they are also underscore some important difference between the geochemical effects observed during field tests on natural soils and those seen in laboratory tests using ideal materials. (Jiann-Long Chen and Larry Murdoch)

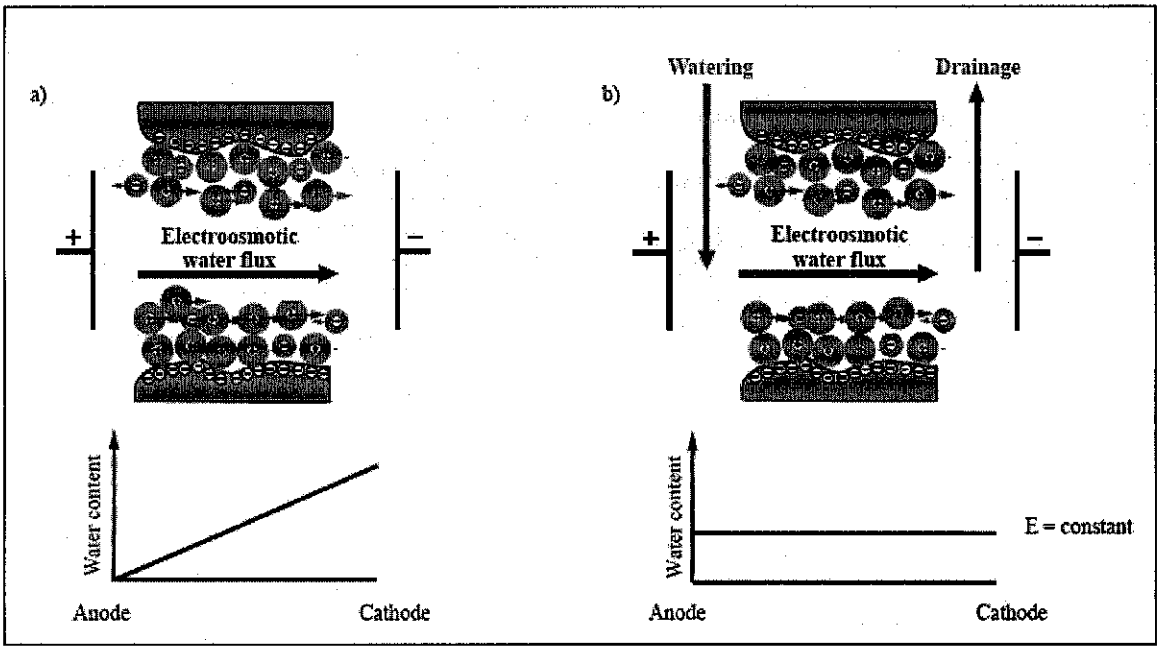

Figure 2.4: Desiccation of the anodic region due to electroosmosis (a) and conservation of soil water content by watering and drainage system (b) {E (electric Field Strength) = Constant}

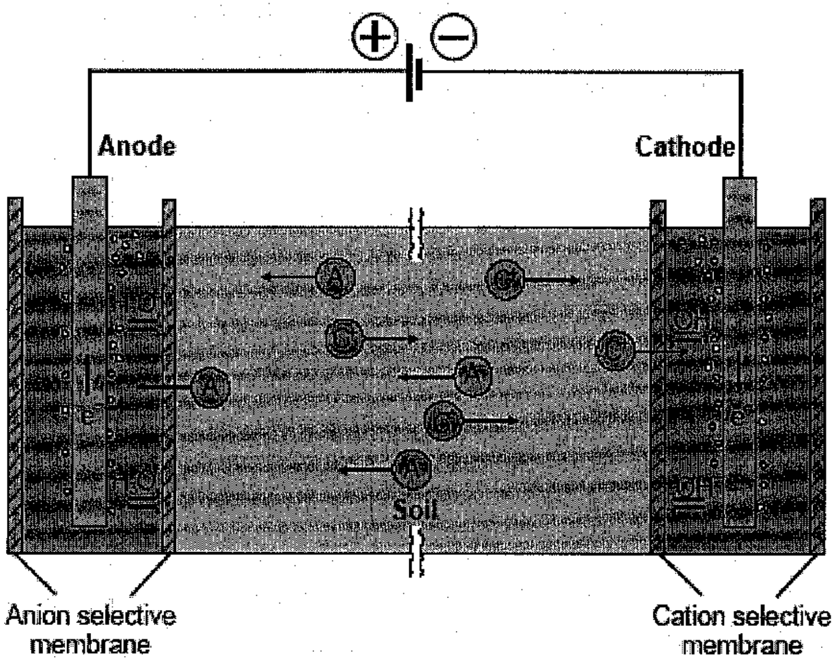

Figure 2.5: Water Impermeable ion-selective membranes

2.3 Slope Stability in General

In most applications, the primary purpose of slope stability analysis is to contribute to be safe and economic design excavations, embankments, earth dams and landfills. The aims of slope stability analyses are

1. To understand the development and form of natural slopes and the processes responsible for different natural features.
2. To assess the stability of slopes under short-term (often during construction) and long-term conditions.
3. To assess the possibility of landslides involving natural or existing engineered slopes.
4. To analyze landslides and to understand failure mechanisms and the influence of environmental factors.
5. To enable the redesign of failed slopes and the planning and design of preventive and remedial measures, where necessary.
6. To study the effect of seismic loadings on slopes and embankments.

7. To observe the effect of using the current to the slopes whether it can strengthen the slope or not.

The analysis of slopes take into account a variety of factors relating to topography, geology, and material properties, often relating to whether the slopes was naturally form or engineered.

2.3.1 Natural Slopes

Natural slopes that have been stables for many years may suddenly fail because of changes in topography, seismicity, groundwater flows, loss of strength, stress changes, and weathering. Generally, these failures are not understood well because little study is made until the failure makes it necessary. In many instances, significant uncertainty exists about the stability of a natural slope. This has been emphasized by Peck (1967), who said: "Our chances for prediction of the stability of a natural slope are perhaps best if the area under study is an old slide zone which has been studied previously and may be reactivated by some human operations such as excavating into the toe of the slope. On the other hand, our chances are perhaps worst if the mechanism triggering the landslide is (1) at random not previously studied location and (2) a matter of probability such as the occurrence of an earthquake".

Knowing that old slip surfaces exist in natural slopes makes it easier to understand and predict the slope's behaviour. Such slip surfaces often result from previous land-slides or tectonic activities. The slip surfaces may also be caused by other processes, including valley rebound, glacial shove, and glacial phenomena such as solifluction and nonuniform swelling of clays and clay-shales. The shearing strength along these slip surfaces is often very low because prior movement has caused slide resistance to peak and gradually reduce to residual values. It is not always easy to recognize land-slide areas (while postglacial slides are readily identified, preglacial surfaces may lie buried beneath glacial sediments). However, once presheared strata have been located, evaluation of stability can be made with confidence.

The materials most likely to exhibit progressive failure are clays and shales possessing chemical bonds that have been gradually disintegrated by weathering. Weathering releases much of the energy stored in these bonds (Bjerrum, 1966). Our understanding of landslides involving clay and shale slopes and seams has increased largely due to original work by Bishop (1966), Bjerrum (1966) and Skempton (1964).

2.3.2 Engineered Slopes

These engineered slopes consist of three main categories which is embankment, cut slopes, and retaining walls. The main focus is more to the cut slopes.

2.4 Cut Slopes

Shallow and deep cuts are important features in civil engineering project. The aim in a slope design is to determine a height and inclination that is economical and that will remain stable for a reasonable life span. The design is influenced by the purposes of the cut, geological conditions, in situ material properties, seepage pressures, construction methods, and the potential occurrence of a natural phenomenon such as heavy precipitation, flooding, erosion, freezing, and earthquakes.

Steep cuts often are necessary because of right-of-way and property line constraints. The design must consider measures that will prevent immediate and sudden failure as well as protect the slope over the long term, unless the slope is cut for temporary reasons only. In some situations, cut stability at the end of construction may be critical design consideration. Conversely, cut slopes, although stable in the short term, can fail many years later without warning. To a certain degree, the steepness of a cut slope is a matter of judgement not related to technical factors. Flat cut slopes, which may be stable for an indefinite period, are often uneconomical and impractical. Slopes that are too steep may remain stable only for a short period of time. A failure may pose a danger to life and property at a later date. Failures could involve tremendous inconvenience and the expense of repairs, maintenance, and stabilization measures.

The Figure 2.3 below shows the general variations of factor of safety, strength, excess pore pressure, load, and shear stress over time for a clay cut slope. The initial shear strength is equal to the undrained shear strength on the assumption that no drainage occurs during construction. In contrast to embankment slopes, the pore pressure within the cut increases over time. This increase is accompanied by a swelling of the clay, which results in reduced shear strength. Thus the factor of safety decreases over time until unstable condition is reached. This, for the most part, explains why clayey cut slopes sometimes fail a long time after initial excavations.

Long-term cut slope stability is also dependent on seepage forces and therefore, on the ultimate groundwater level in the slope. After excavation, the free-water surface will usually drop slowly to a stable zone at a variable depth below the new cut surface. This drawdown usually occurs rapidly in cut slopes made in sand but is usually much slower in clay cut slopes. Although typical rates and shapes of groundwater drawdown curves have been proposed for cut slopes, none has proved useful for correctly predicting the time or rate of drawdown or preconsolidated clays. The main obstacle to such prediction comes from the difficulty in correctly modelling the recharge of the area.

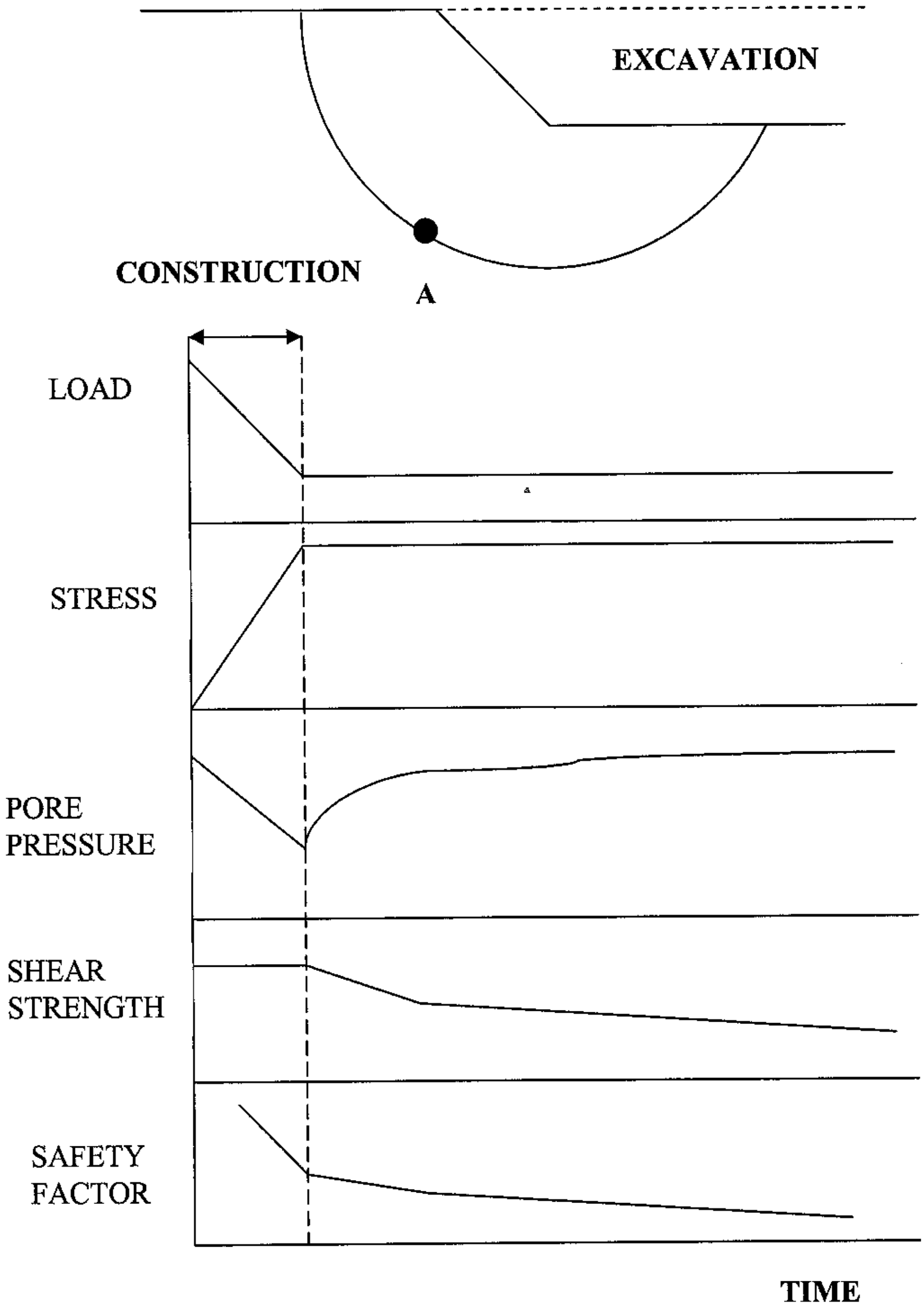

Figure 2.6: Stability conditions for a cut slope. (From Bishop and Bjerrum, 1960, reproduced by permission of ASCE.)

In general, there are no specific data or result that works as an electrokinetic is the best application for the slopes. However, according from many researchers this method is very rare in the slope stabilization practice. From the literature review, if the electrokinesis is workable for stability purposes especially in slopes, it can be the most practical methods among the other method.

2.5 Kaolinite (White China Clay)

Kaolinite is used to obtain artificial pozzolans from its calcination product. Unfortunately, it does not occur in natural conditions as a pure phase but always mixed in various proportions with many secondary minerals. Among them, quartz is one of the most common associated minerals. Natural clays, mainly composed of kaolinite and quartz, have been burnt at 600, 700 and 800¡C and the calcination products have been characterized by XRD supplemented by SEM observations and granulometric analysis, in order to determine the quartz influence on kaolinite calcination. Mechanical strength tests on portlandite/calcination products pastes have been performed and compared to those obtained on pastes prepared from quartz added to burnt kaolin. Results allow to ascertain the role of quartz as a function of the burning temperature, the burning time, the water/solid ratio on the development of mechanical strength.

It is well recognized that blending pozzolanic material with Ordinary Portland Cement (OPC) results in enhanced performance of mortars and concretes. The enhanced performance includes, for instances, level of long term strength, lower permeability, reduced diffusion coefficients, increased sulfate resistance. Many of these features are closely linked to the refinement of the pore structure by the pozzolanic materials.

Thermal activation of natural clays is one of the most interesting choice to obtain pozzolans and the properties of such products has received extensive attention. Among clay deposits, kaolinitic clays are considered in the literature as the most adequate raw material for production of pozzolans by thermal activation.

However, it must be pointed out that the development of pozzolanic properties from kaolin will depend strongly on the deposits that can be highly variable in amount of kaolin, in mineralogy and chemical composition and also the calcination conditions (time and temperature).

Therefore, an investigation has been carried out to assess quantitatively the effect of mineralogical variability of natural clay deposits, mainly composed of kaolin and quartz, on the rheology and the development of compressive strength of pastes composed of calcined products and portlandite taking into account various burning conditions.

Properties of Kaolinite	
Liquid Limit, LL	66%
Plastic Limit, PL	31.31%
Specific Gravity, G_s (Braja M. Das, 1941)	2.60
Plasticity Index, I_p	34.69%
Moisture Content	39.94%

Table 2.1: Properties of Kaolin from Testing in UTP Laboratory

TABLE 3 : Composition and Properties of Kaolin

Property	Value
Mineralogy	Kaolinite: 100%
	Muscovite: trace
	Illite: trace
Particle Size Distribution (ASTM D 422)	
Gravel	0%
Sand	4%
Silt	18%
Clay	78%
Atterberg Limits (ASTM D 2487)	
Liquid Limit	50.0%
Plastic Limit	27.4%
Plasticity Index	22.6%
Specific Gravity (ASTM D 854)	2.60
Moisture-Unit Weight Relationships	
(Harvard Miniature Compaction Test)	
Maximum Dry Unit Weight	14.4 kN/m^3
Optimum Moisture Content	27%
Hydraulic Conductivity	1.0×10^{-8} cm/sec
Cation Exchange Capacity (ASTM D 9081)	1.0-1.6 meq/100 g
pH (ASTM D 4972)	4.9
Organic Content (ASTM D 2974)	Near 0%
USCS Classification (ASTM D 2487)	CL

Table 2.2: Composition and Properties of Kaolin (Indian Geotechnical Journal, 2002)

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The project methodology and procedure is divided into four (4) main categories as below:

3.1.1 Literature Review and Information Gathering

Information on electrokinesis application especially with regards to the slope stability, selection of the electrodes and the voltage can be used are gathered from various identical books, journals, encyclopedia and thesis that have been developed earlier by internal and external parties. Only the necessary information is picked based on the importance to suite the scope of the research. The relevant information and data is studied in depth and thoroughly.

3.1.2 Laboratory Work (Kaolinite properties)

Laboratory work covers the preparation of the models of the slope itself and the kaolinite soil which will be used in the testing. Testing also including the properties of the kaolinite soil.

3.1.2.1 Sieve Analysis

Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings. Using BS 1377: Part 2: 1990: 9.2/9.3/9.4.

Sieve mesh size (mm)
3.35
2.0
1.18
0.600
0.425
0.300
0.212
0.150
0.063
Pan

Table 3.1: Sieve Size

To conduct a sieve analysis, one must first oven-dry the soil and then breaks all lumps into small particles. The soil is then shaken through a stack of sieves with openings of decreasing size from top to bottom. After the soil is shaken, the mass of soil retained on each sieve is determined. Once the percent finer for each sieve is calculated, the calculations are plotted on the semilogarithmic graph paper with percentage finer as ordinate and BS sieve aperture sizes (mm) as the abscissa (Refer to the Appendices). This plot is referred to as the Particles-size distribution curves.

3.1.2.2 Grading Characteristics

A grading curve is a useful aid to soil description. Grading curves are often included in ground investigation reports. Results of grading tests can be tabulated using geometric properties of the grading curve. These properties are called grading characteristics.

First, three points are located on the grading curves:

d_{10} = the maximum size of the smallest 10% of the sample

d_{30} = the maximum size of the smallest 30% of the sample

d_{60} = the maximum size of the smallest 60% of the sample

The cumulative percentage quantities finer than certain sizes are determined by weighing. Points are then plotted of percentage passing (finer) against log size. A smooth S-curve drawn through these points is called grading curve. The position and shape of the grading curve determines the soil class. Geometrical grading characteristics can be determined also from grading curve.

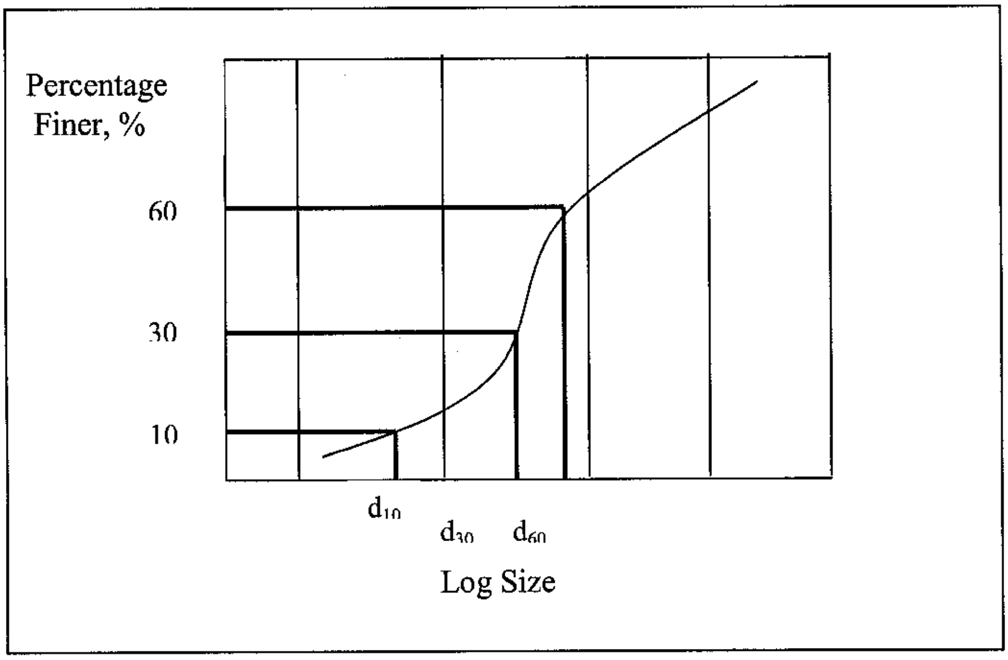

Figure 3.1: Grading Curve

3.1.2.3 Liquid Limit and plastic Limit (Cone Penetrometer)

The liquid limit is the empirically established moisture content at which a soil passes from the liquid state to the plastic state. Referring to the BS 1377: Part 2, using the Penetrometer, the liquidity of the kaolinite is defined. To carry out this testing, the soil is taken from the sieves which is 300g passes 0.425mm test sieve. The soil sample is placed on the glass plate and added some water to mix the paste. Then, the mixed is put into the cup with spatula and to make sure not trap the air. Using the penetration cone locked, it is raised in position and the supporting assembly is lowered so that the tip of the cone just touches the surface of the soil. The sample is moved slightly just to mark the soil surface. The stem of the dial gauge is lowered to contact the cone shaft and the reading is zero and so zero shaft. The timer on the automatic controller is set to 5s and the release button is press. About 5s, the controller will lock the cone shaft. The stem of dial gauge is lowered to contact the cone shaft and the reading is taken to the nearest 0.1mm. The reading is recorded as the cone penetration. The test is repeated of the same soil sample which is adding some distilled water. The amount of distilled water added is the range of penetration values of approximately 15mm to 25mm is covered b the four or more tests run and is even distributed.

The plastic limit is defined as the moisture content, in percent, at which the soil crumbles, when rolled into threads of 3.2mm in diameter. The plastic limit is the lower limit of the plastic stage of soil. The plastic limit test is simple and is performed by repeated rollings of an ellipsoidal-size soil mass by hand on a ground glass plate. The procedure for the plastic limit is given by BS 1377: Part 2. The testing is conduct by weighing 20g sample of soil which is passing through 0.425mm test sieve and is placed in the glass plate. The soil is allowed to dry until it becomes plastic enough to be shaped into a ball. The ball of soil is mould between the fingers and is rolled between the palms of hands until the heat of the hands will dried the soil for slight cracks to appear on its surface. Then, the sample is divided in two sub-samples of about 10g each and is carried out the determination of each portion. The sub-sample then is divided into four more or less equal parts. The next step is the sample is mould using finger to equalize the distribution of moisture content and the soil is thread about 6mm diameter . The thread is rolled again to reduce diameter to3mm in 5 to 10 complete forward and back movement. The test is repeated until the thread shears both longitudinally and transversely when it is rolled about 3mm diameter. After the soil is crumbled, the piece of soil is not gathering together in order to reform the thread and to continue rolling. The first crumbling point is the plastic limit.

3.1.2.4 Vane Shear Test

The shear vane usually consists of four thin, equal sized steel plates welded to a steel torque rod. This method is covered the measurements of the shear strength of a sample of soft to firm cohesive soil without having to remove it from container or sampling tube. The sample therefore does not suffer disturbance due to preparation of a test specimen. To carry out this testing, the sample container is attached securely to the base of the vane apparatus, with the sample axis vertical and located centrally under the axis of the vane. A torsion spring that is most appropriate is selected for the estimated strength of the soil and assembles it into the vane apparatus which in Appendix 3-1 Figure 3.2 and Table 3.2. The pointer and the graduated scale on the torsion head is set to their zero readings, and is ensure that there is no backlash in the mechanism for applying torque. Then, the vane assembly is lowered until the end of the vane just touches the surface of the sample. This provides the datum from which the depth of penetration of the vane can be measured. The vane assembly is lower further to push the vane steadily into the sample to the required depth. The top of the vane should be at distance not less than four times the blade width below the surface. The depth penetration is recorded. The testing is started by applying torque to the vane by rotating the torsion head at the certain rate until the kaolin soil has sheared. The deflection of spring and the rotation of vane are taken from the angular scale.

3.1.2.5 Testing without Electrokinetic

3.1.2.5.1 Sample Preparation

A residual kaolin soil is taken from the factory area at Bidor in 1m to 2m depth. The soil was air dried under the laboratory condition, after the plant roots were removed. The sample then broken up using sieve machine. Before any testing was carried out on the soil, the sieved soil was mixed thoroughly in order to ensure the homogeneity of the sample. After the thorough mixing, the sample was kept in a large plastic beg. The plastic beg was securely tied to prevent or minimized the effect from the surrounding and also to keep the moisture.

The testing is run by designing the slope model with 45^0 angles. The early stages of the experiments the box with 12"x 12" was used for testing as shown in Figure 3.6. The box was laid with the geotextile at the bottom and is filled with 2mm layer of the sand to represent the actual slope at site. The soil was mixed with a weight of water and well blended together using the mixer. The sample was left for eight, twelve and seventeen days. At the end of the designated day, the sample was taken using the *auger* for testing. The testing includes moisture content and also the shear strength for every different day. The sample is taken from various locations along the slope. The purpose is to see if there is a different in terms of the strength and moisture content for the soil itself. For the 8 day experiment, the testing used the actual box with 9"x 16". The same procedure was used for this testing.

3.1.2.6 Testing using Electrokinetic

The electrokinetic cell used in the study basically consisted of two power DC supply and a box with a dimensional of 9"x16" to accommodate the model of kaolin slope, a cover and geotextile laid at the bottom of the box. The accessories comprised six steel electrodes placed into the top of the cover as shown in Figure 3.4. The cover of the box consist six holes ½" diameter alignment to the base of box. A DC power converter with capacity of 40V was used in this study to supply electricity. The schematic diagram of the electrokinetic experiment is illustrated in Figure 3.3.

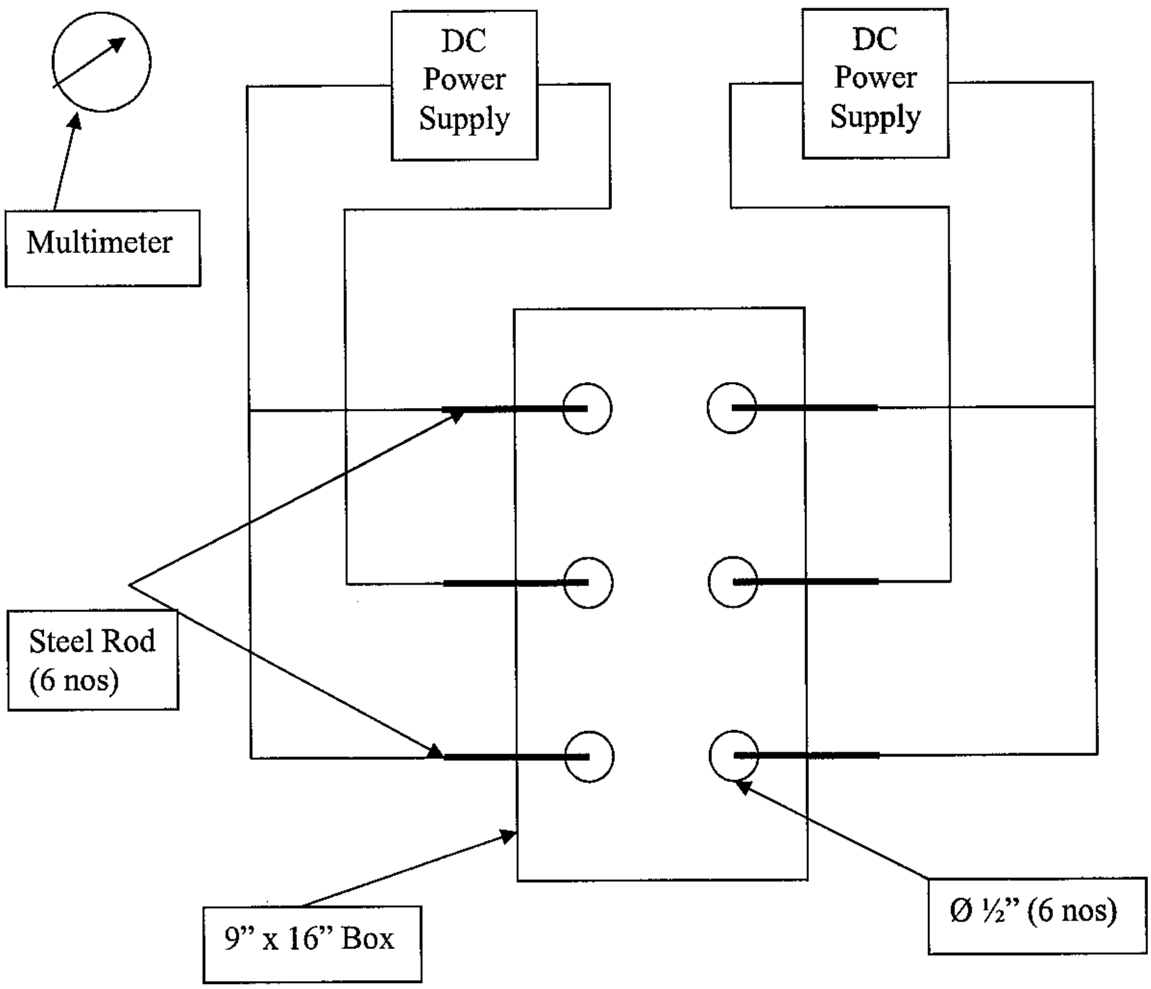

Figure 3.3: Schematic diagram of the general layout of electrokinetic experiment

Kaoline Soil with 5kg weight and the 2.8kg of water was used in this test by factor of 1.0 or 1.25 of Plastic Limit. The distilled water was used in mixing the soil. The slope was built in the box and the rods were accurately placed in the holes provided on top of its cover. The box is fabricated so as to be leak-proof and this was done by using epoxy on all the joints. This precaution was important to ensure that water would only flow through the soil and through the six holes provided not through the wall of the box. The experiment was conducted by using 10V in the beginning and then continued with 20V and 30V within 8 day each. These values were chosen since the purpose of experiment is to monitor the behavior of the slope in the small scales. Since the applied voltage was held constant, the interrelated factor such as resistivity, current density, voltage gradient, temperature and other factors result the variation in the reading. Again, the main focus of this study is to observe the phenomenon of electrokinetic process in kaoinite slope.

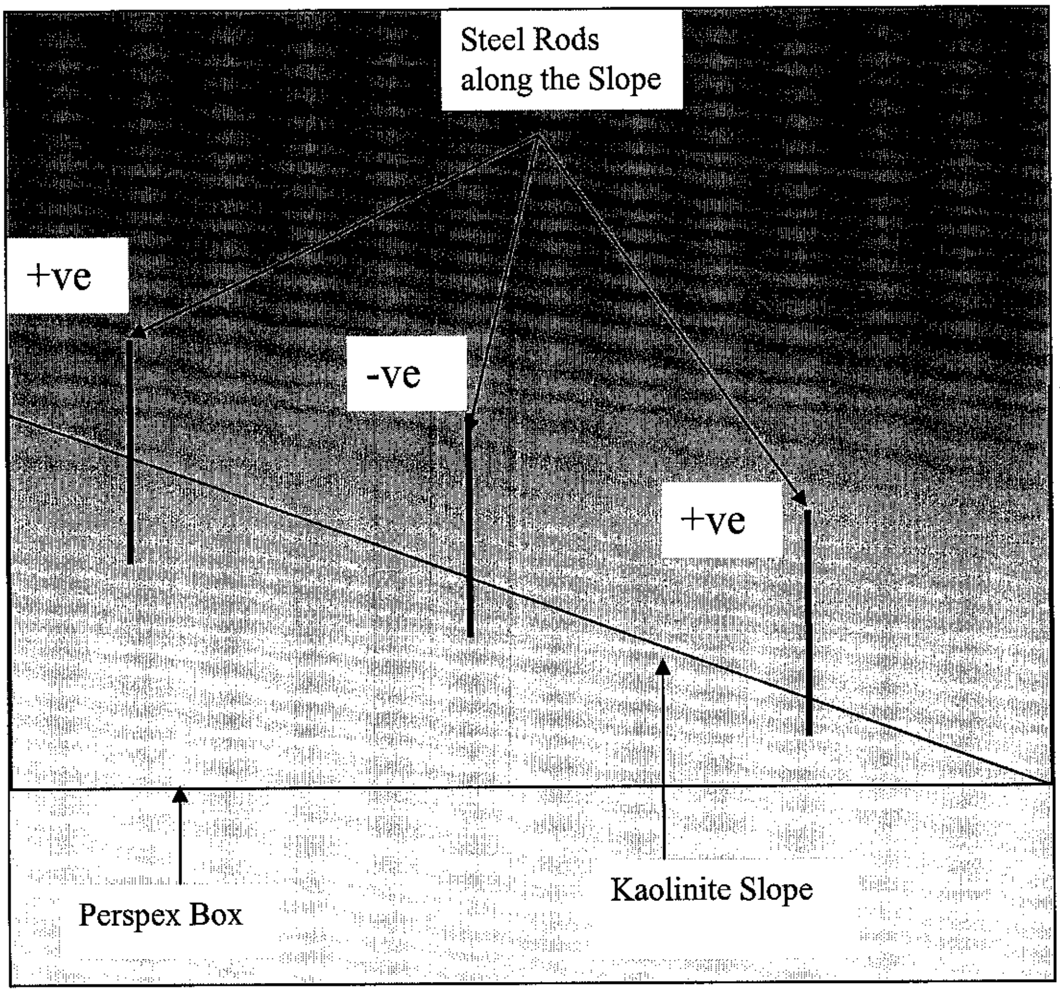

Figure 3.4: Arrangement of Rods along the Slope

3.2 Tools Required

3.2.1 Experimental equipment

The model basically represents the working slope at site. The size of this model is 9" x 16"in Figure 3.5 and the other one was 12" x 12" for Figure 3.6, all from Perspex for the support facilities. The instrumentation of the models such as the rod, gauge reading, multimeter, DC Power Supply which in Figure 3.6 (1) and others was ordered from the suppliers.

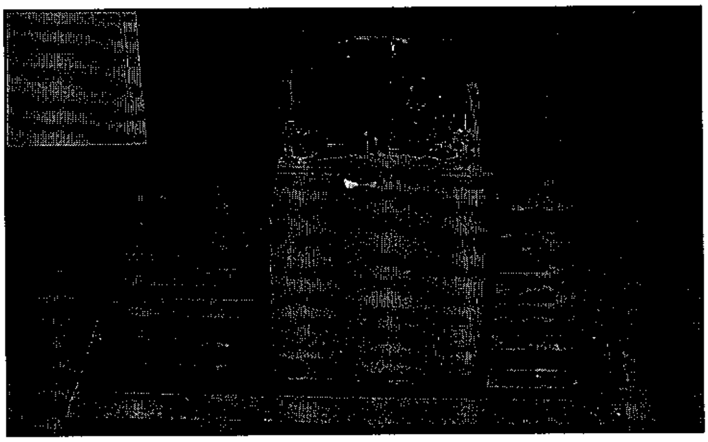

Figure 3.5: The Perspex Box Model

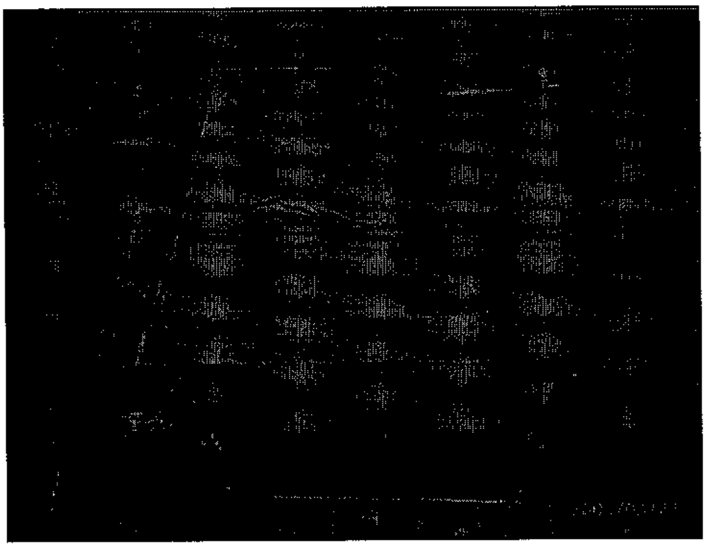

Figure 3.6: The Perspex Box Model used without Electrokinetic

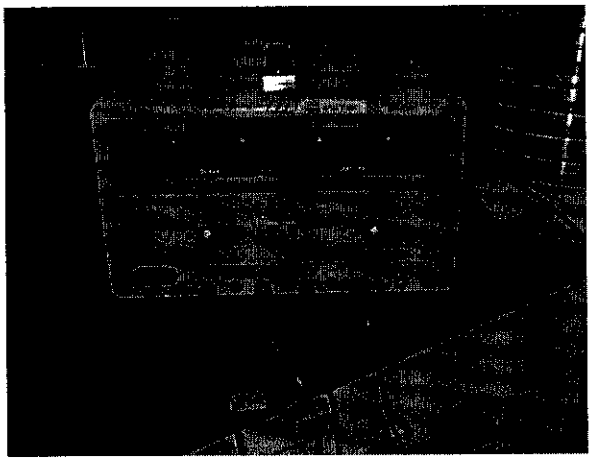 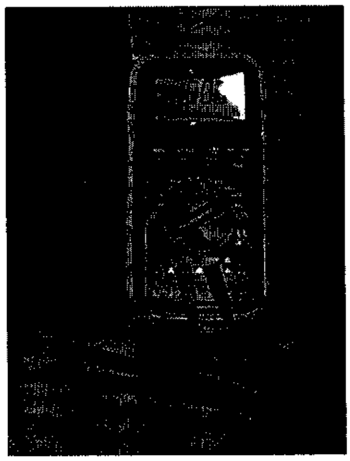

Figure 3.6 (1): DC Power Supply and Multimeter

3.2.2 Software

Microsoft EXCEL or LOTUS 123 is used to present the experimental results in form of tables and graphs.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 FINDINGS

Through the study, the electrokinetic technique was found to be effective as the method successfully stabilize the kaolinite slope in term of the increasing it strength and also the moisture content of the soil sample. However, the different arrangement and configuration of the rods along the slope was found to produce the different results than the normal arrangement of steel rods. It shows some positive phenomenon when different Voltage was applied to the soil sample ranging from 10 Volt to 30 Volt. The duration of each experiment using electrokinetic technique was run within 8 days and data was recorded which includes the currents, strength of the soil and the moisture cotent of the sample after the process.

4.2 LABORATORY EXPERIMENTS

Several variables or parameters have been selected to be manipulated during the experiments carried out in the laboratory using the model which is already fabricated (*See Figure 4.0*). In these experiments consists of two parts where the first part was done without applying the current to the slope and it was conducted in 8, 12 and 17 days long. For each duration, thee three factors were monitored which were strength, moisture and the behavior of the slope. In the second part of the experiments tests were done using the electrokinetic technique (*See Figure 4.1*). The experiments utilized 10Volt, 20 Volt and 30 Volt respectively to the slope within eight days. All the factors observed in the part one were also observed in this second part experiments for comparison purposes.

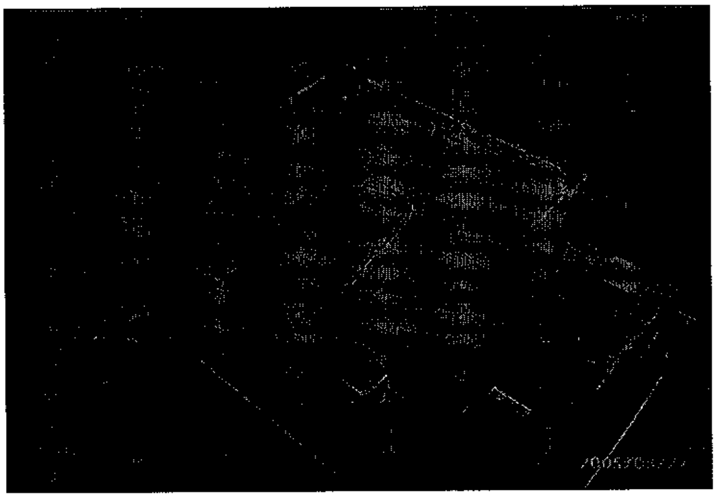

Figure 4.0: Model of the Perspex Box (Part One)

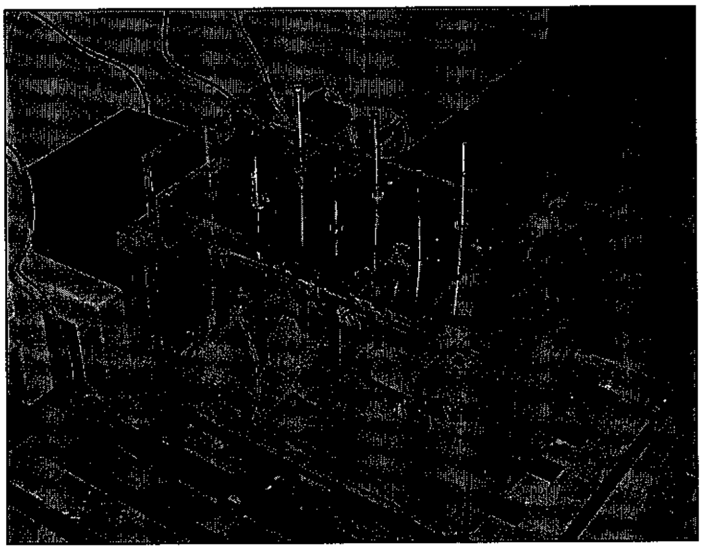

Figure 4.1: Model of the Box (Part Two)

4.2.1 Sieve Analysis

The grading curve has been plotted on special semi-logarithmic paper. From the graph that has been plotted, the kaolinite soil is classified as well-graded gravelly Sand. It comprises gravel, coarse sand, medium sand, and fine sand.

The particles sizes distribution also can be used to determine the following parameter as stated below. First, three points are located on the grading curves:

d_{10} = the maximum size of the smallest 10% of the sample

d_{30} = the maximum size of the smallest 30% of the sample

d_{60} = the maximum size of the smallest 60% of the sample

From these the grading characteristics are calculated:

Effective size, d_{10}

Uniformity coefficient, $C_u = d_{60} / d_{10}$

Coefficient of gradation, $C_k = d_{30}^2 / d_{60} d_{10}$

Both C_u and C_k will be one for a single-sized soil.

$C_u > 4$ indicates a well-graded soil

$C_u < 4$ indicates a uniform soil

$1 < C_k > 3$ indicates a well-graded soil

$C_k < 1$ indicates a possible gap-graded soil

The effective size, d_{10} of the sample is 3.36mm, d_{30} of the sample is 1.17mm, and d_{60} is 0.155mm. The Uniformity coefficient, C_u of the sample was calculated as 0.46 and the Coefficient of gradation, C_k as 2.6. Following the above classification of the soil, the kaolin soil indicates a uniform soil and also indicates a well-graded soil.

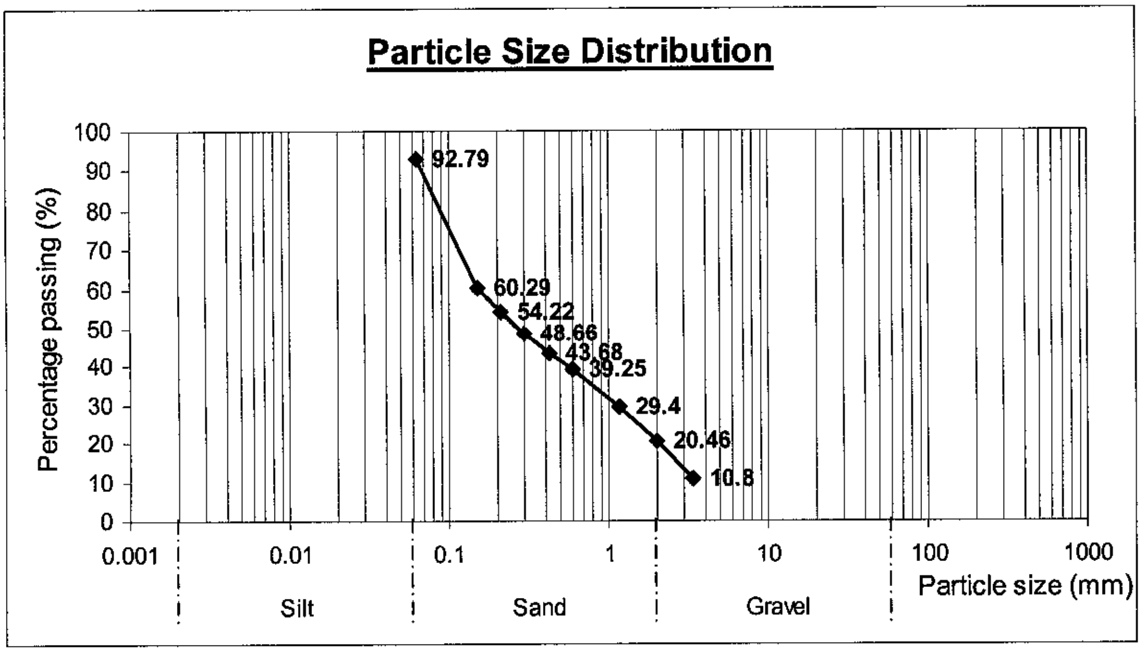

Figure 4.2: Particle Size Kaolinite Soil

4.2.2 Liquid Limit and Plastic Limit

From the graph that has been plotted, which penetration of cone (mm) against moisture content (%), the liquid limit (LL) of the soil sample is corresponding to a cone penetration of 20mm as LL= 66.0. Consistency varies with water content in the soil. The consistency of a soil can range from (dry) *solid* to *semi-solid* to *plastic* to *liquid* (wet). The water contents at which the consistency changes from one state to the next are called consistency limits or Atterberg limits. The liquid limit (W_L) is the change of consistency from plastic to liquid.

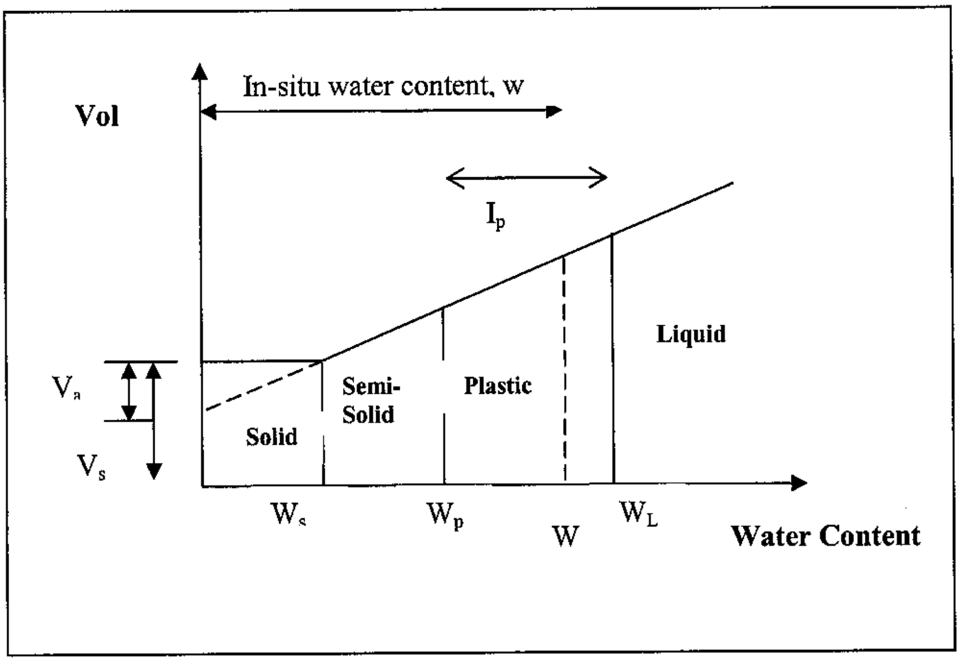

Figure 4.3: Consistency Limits and Plasticity

The average of the moisture content for two samples:

$$= \frac{31.29 + 31.32}{2} = \mathbf{31.31}\ \%(\text{ PL})$$

The consistency of the most soils in the ground will be plastic or semi-solid. Soil strength and stiffness behavior are related to the range of plastic consistency. The range of water content over which soil has a plastic consistency is termed as Plasticity Index (I_p or PI).

Therefore the Plasticity index, $I_p = LL - PL$

$$= 66.0 - 31.31 = 34.69\ \%$$

LOW PLASTICITY	$W_L = < 35\%$
Intermediate plasticity	$W_L = 35 - 50\%$
High plasticity	$W_L = 50 - 70\%$
Very high plasticity	$W_L = 70 - 90\%$
Extremely high plasticity	$W_L = > 90\%$

Table 4.1: BSCS Fine Soils

4.2.3 Strength (Vane Shear Test)

4.2.3.1 Experiment Without Electrokinetic

Study performed on this particular soil in the first part of this experiment without eletrokinetic was showed the strength of the soil gradually increased from the 8 days until 17 days. Three samples were taken from the different location along the slope which is call sample1, sample 2 and sample 3 (*See Figure 4.8*) and the average of the strength was plotted (*See Figure 4.4*). During the 8 days experiment, the samples from the three locations showed that variation of strength of soil along the slope with respect to the time. For the sample location 1, the strength of the soil was found to keep increasing when the experiment took place (*See Figure 4.5 to Figure 4.7*). Those graph also performed that the sample location 2 which is the middle of the slope almost the lowest strength measured between 36.36 kPa to 1286.2 kPa. The calculation of the strength was carried out by determination of the torque applied to shear the soil, M (Nmm) by multiplying the maximum angular rotation of the spring (in degrees) by the calibration factor. The vane shear strength of the soil, τ_v (in kPa) was calculated. Refer to Appendix 4-1.

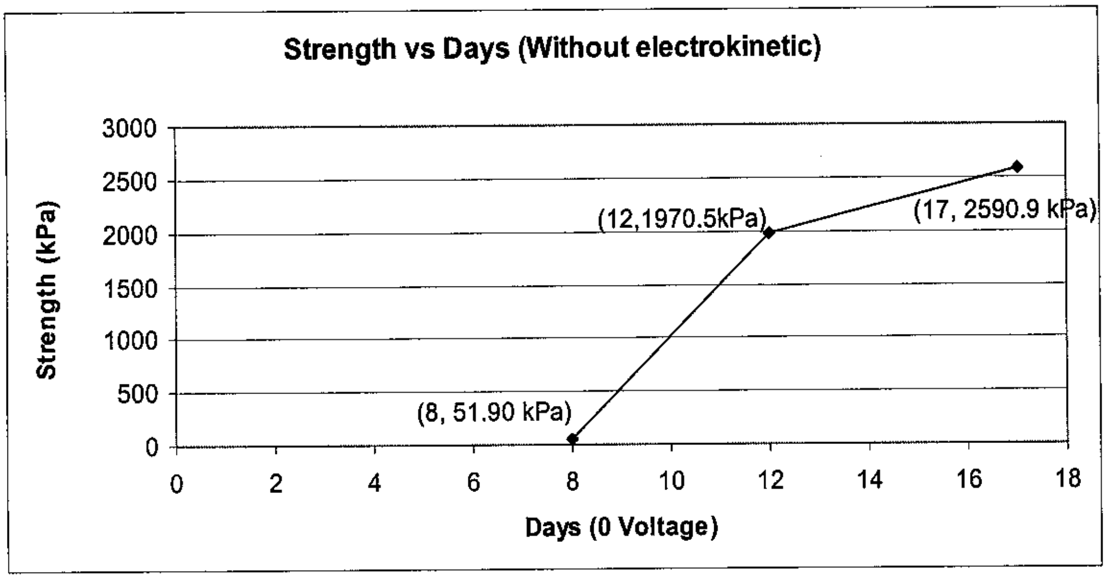

Figure 4.4: Strength of the soil versus Days of the Experiment

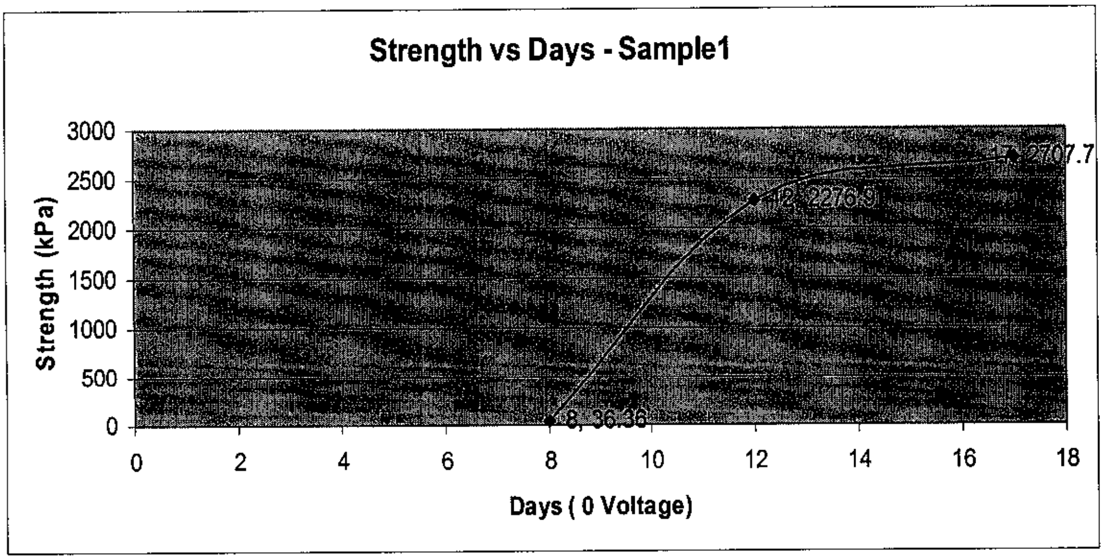

Figure 4.5: Strength of Soil versus Days for Sample Location 1

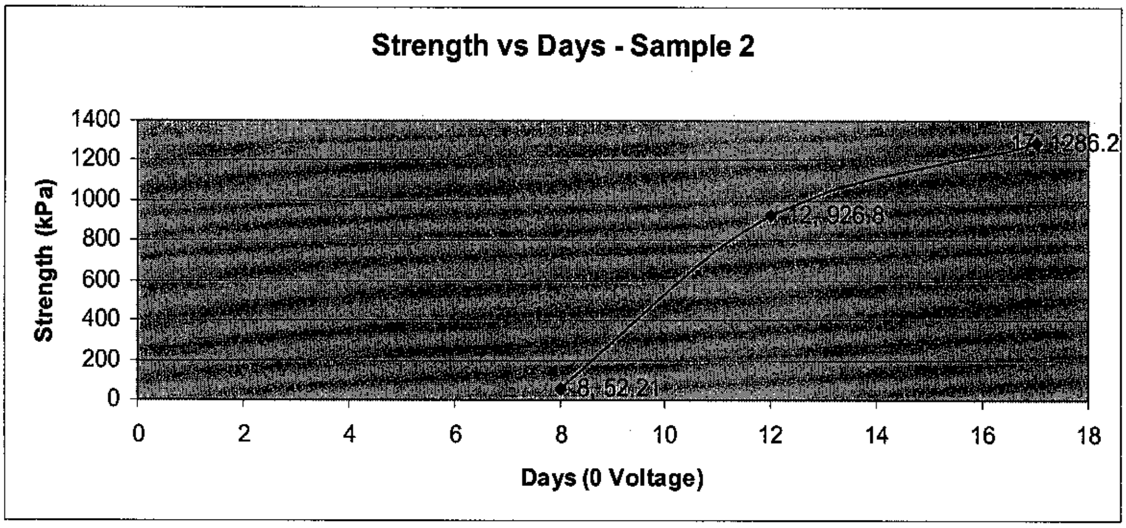

Figure 4.6: Strength of Soil versus Days for Sample Location 2

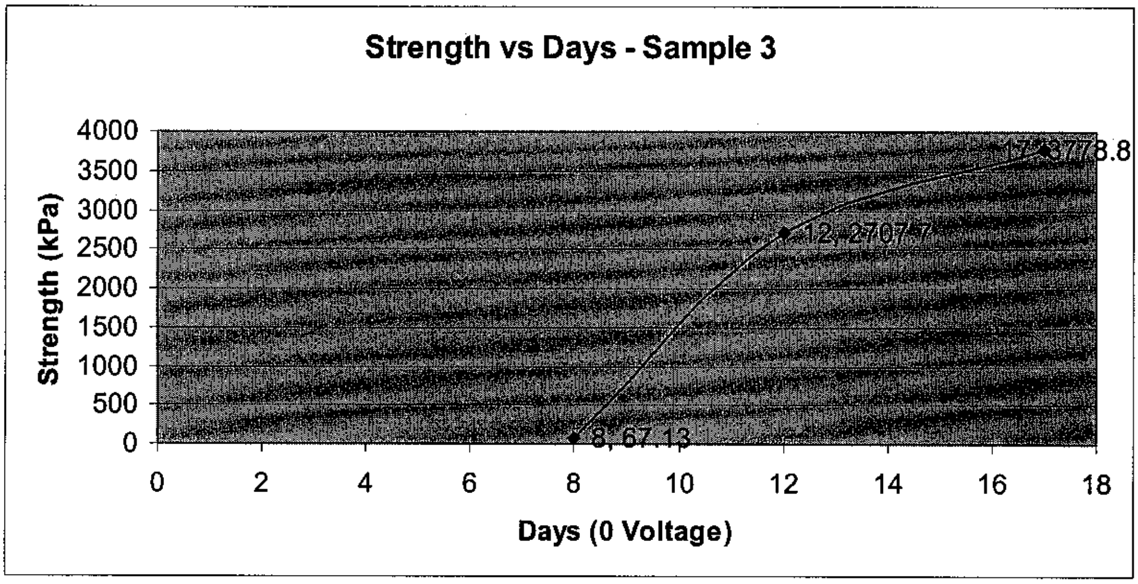

Figure 4.7: Strength of Soil versus Days of Sample Location 3

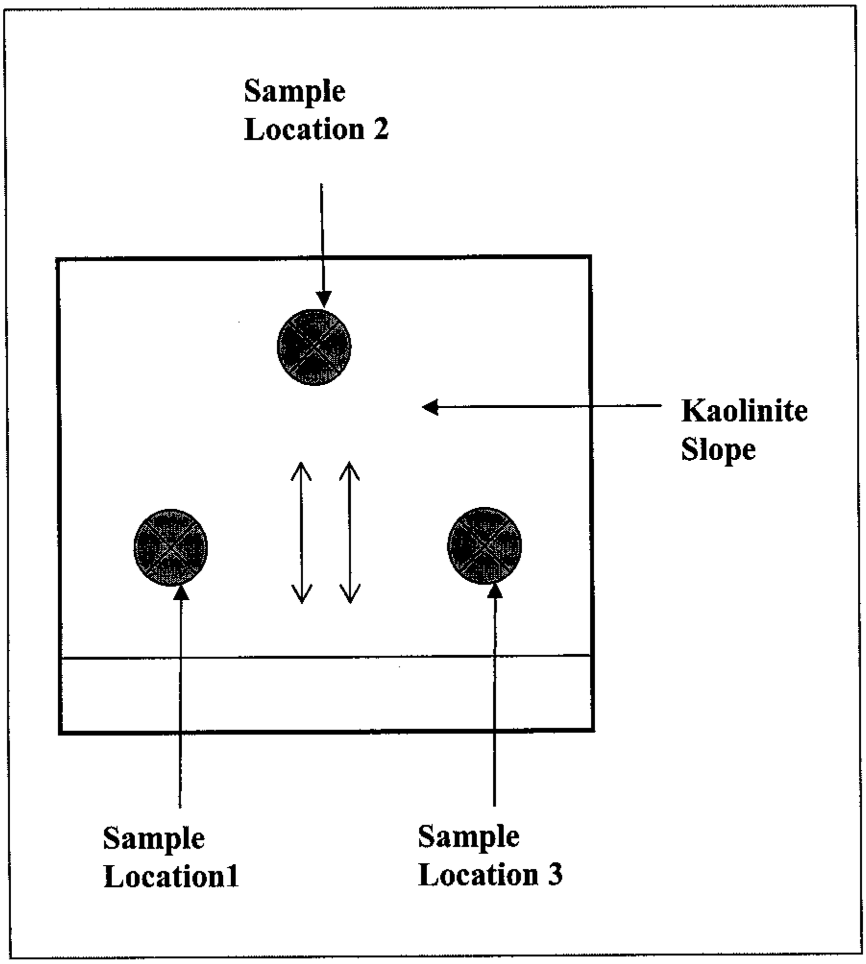

Figure 4.8: Sample Location along the Slope

4.2.3.2 Experiment Using Electrokinetic

Since the electroosmotic permeability of soil is independent of pore size, the variation of the value is thus influenced by the soil water system. In this test, the selected voltage was chosen to apply to the slope which is 10 Volt, 20 Volt and 30 Volt. The experiment was carried out under the laboratory temperature and the effect of temperature in this experiment was ignored. At the end of the experiment which is within eight days for each different voltage, the graph has been plotted against the voltage which is Figure 4.10 to Figure 4.18 was successfully gained. The soil sample was taken in the various places along the slope as shown in Figure 4.9. The sample taken much closed to the rods because the effect of the different charges migrates from anodes to cathodes may effect to the strength of the soil. After analysis, it is found that the shear strength of kaolin soil was kept increasing from 10 volt to 30 volt even the difference is so small but it showed that the electrokinetic effect was there. The phenomenon in stabilizing the slope can be assumed successful. By comparing the exact value which is gained from the experiment with the part one experiment without current shows that the strength is quite low and the highest strength only 37.17 kPa. The graph from Figure 4.12 and Figure 4.13 was shown that the strength still increasing gradually when the higher voltage was applied. The same result was analyzed from the other sample location which gave the increasing of strength for each sample respectively (*See Figure 4.14 to Figure 4.18*). Even though the strength was increased in sample location 1, 2 and 4 but the strength was decreased gradually in sample 3 which the location is in the middle of slope. The samples taken exactly near the rod (Cathodes) and there were also some cracks appeared in the middle of the slope (See Appendix 4-2 Figure 4.19, Figure 4.20, Figure 4.21 and Figure 4.22). Theoretically the cations will migrate through to the cathodes as same as the flow of water towards the cathodes. Therefore, the area around the cathodes will caused ponding. It also effect of the higher voltage which is 30 volt may cause the migrating of water faster than the low voltage. Furthermore, the moisture content in that area is higher because the ponding effect as discuss above. The higher content of water was found at the cathodes because of the migrating water towards the cathodes. The further discussion on the moisture content will follow in the next topics. The graphs plotted to the location of the sample indicate the same patterns in terms of the strength in each placed which in Appendix 4-3 Figure 4.23 to Figure 4.29. The analysis also was done using the 20 volt for different arrangement of the cathode and anode on the slope. The graph plotted indicates the differences. Refer Appendix 4-3Figure 4.30 for the trend of the line. It clearly shows the contradiction with normal arrangement of the cathodes and anodes by using 20 volt. Regarding to its strength, it was definitely increased for the normal arrangement but it was decreased from sample location 1to sample location 4 for the new arrangement of cathodes.

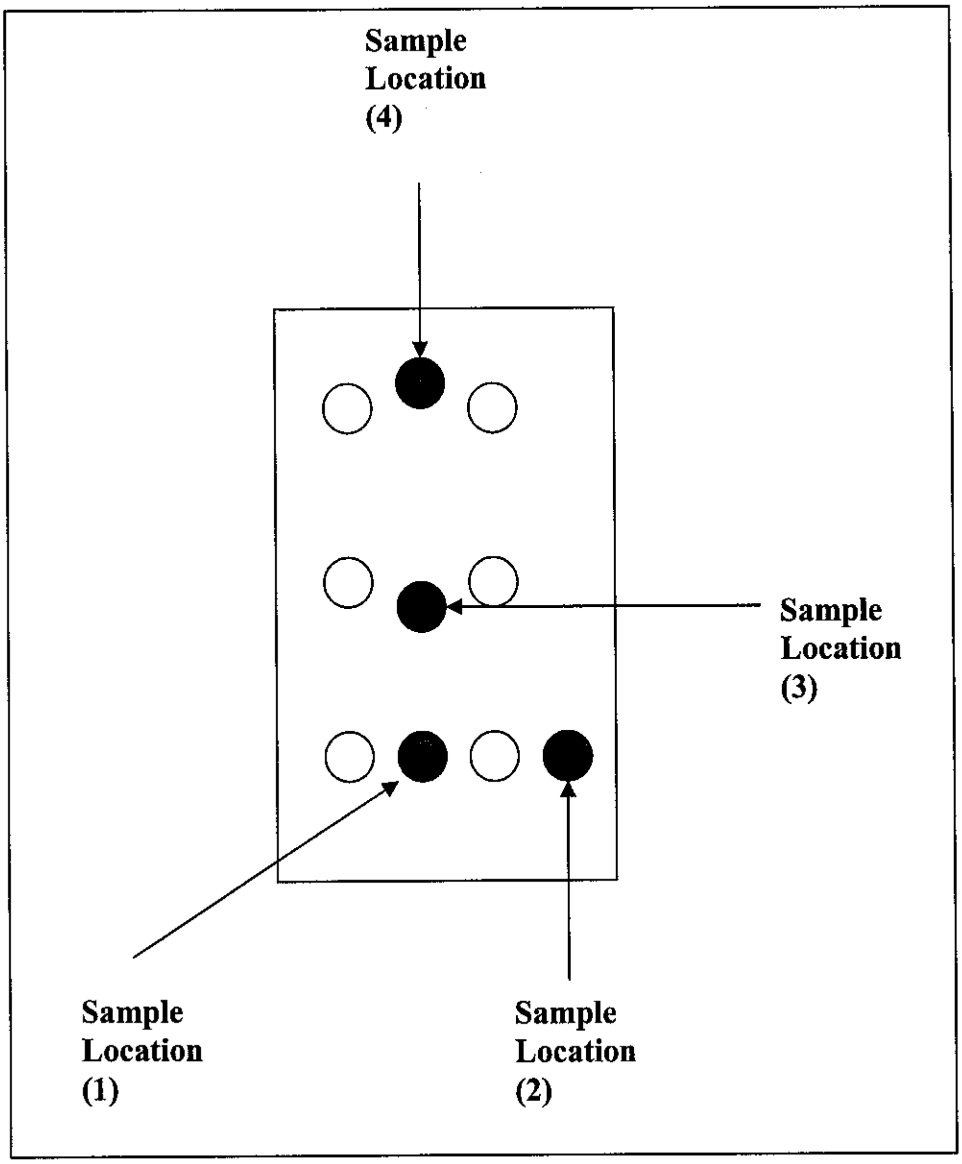

Figure 4.9: Schematic Diagram Shows Sample Location along slope

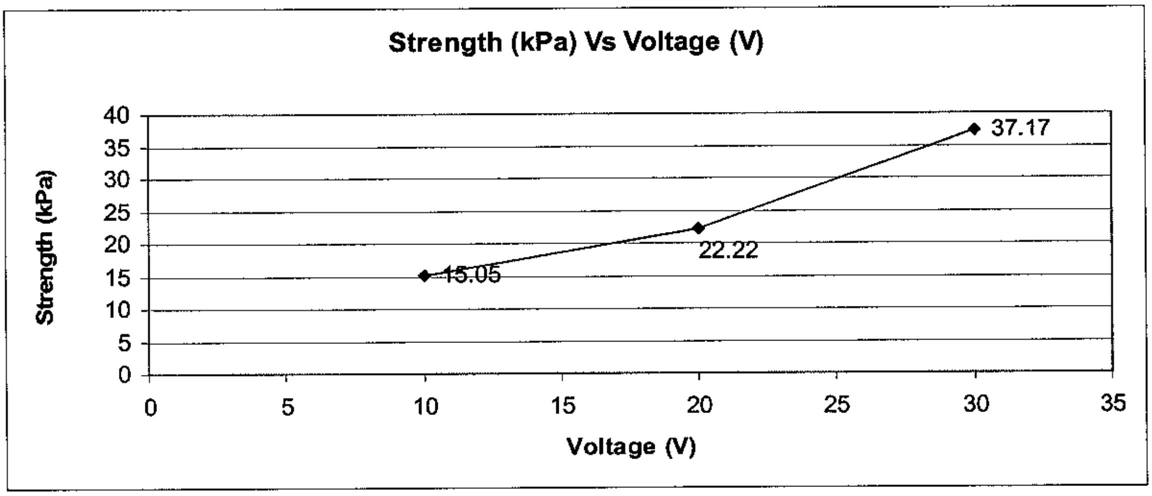

Figure 4.10: The Average Strength versus Applied Voltage

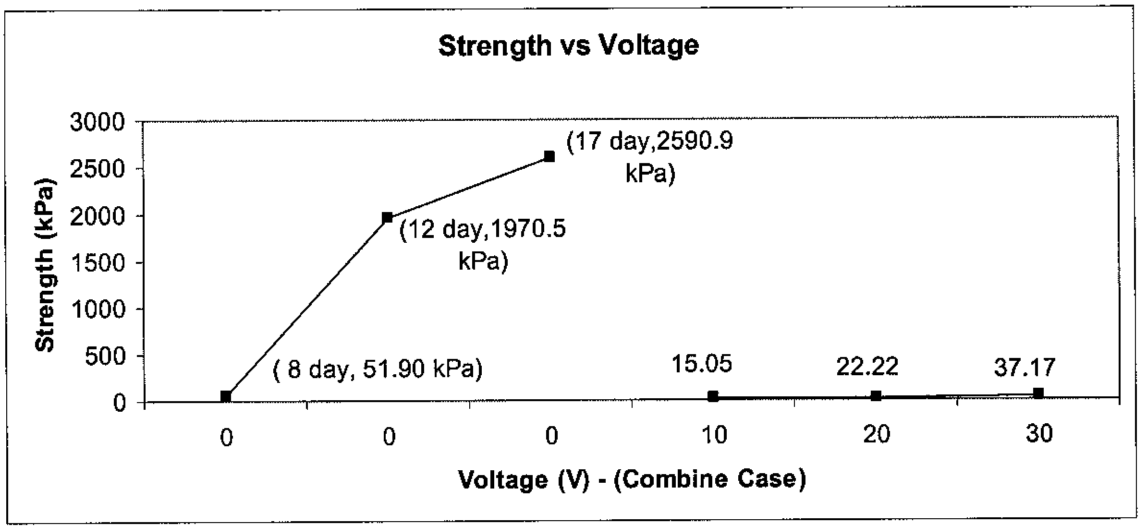

Figure 4.11: The Comparison of the Strength with/without Electrokinetic

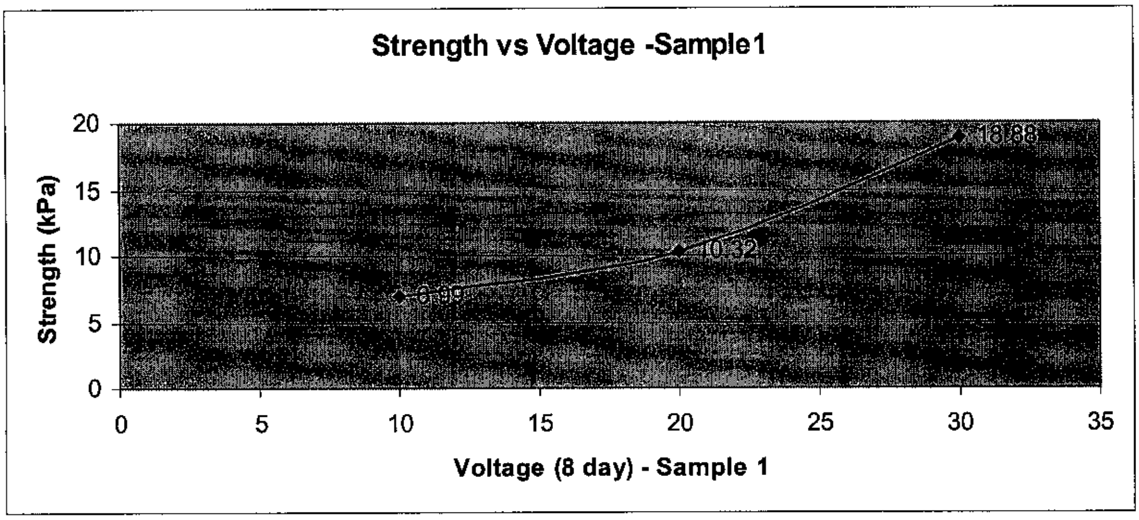

Figure 4.12: Strength versus Sample Location 1

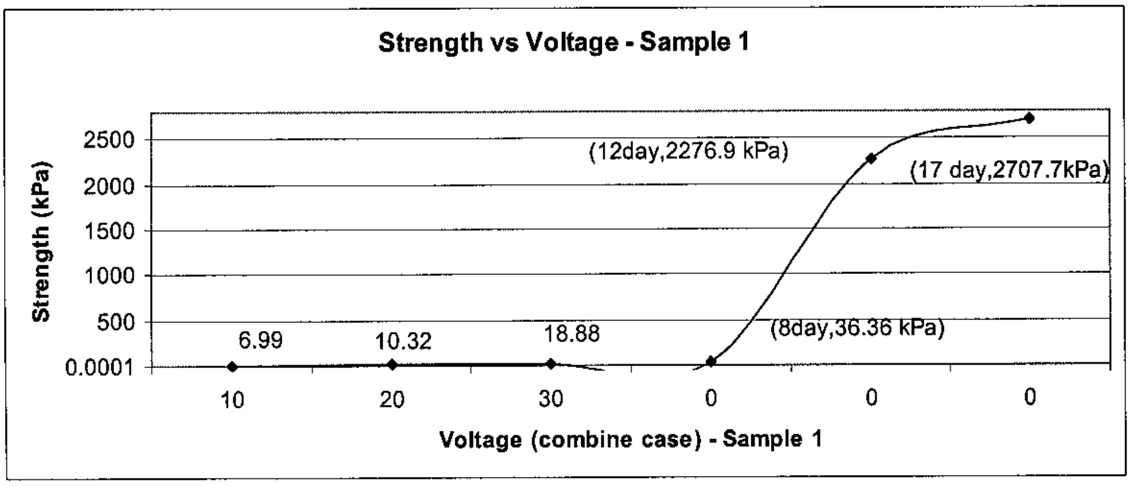

Figure 4.13: Comparison with/without Electrokinetic in Sample Location 1

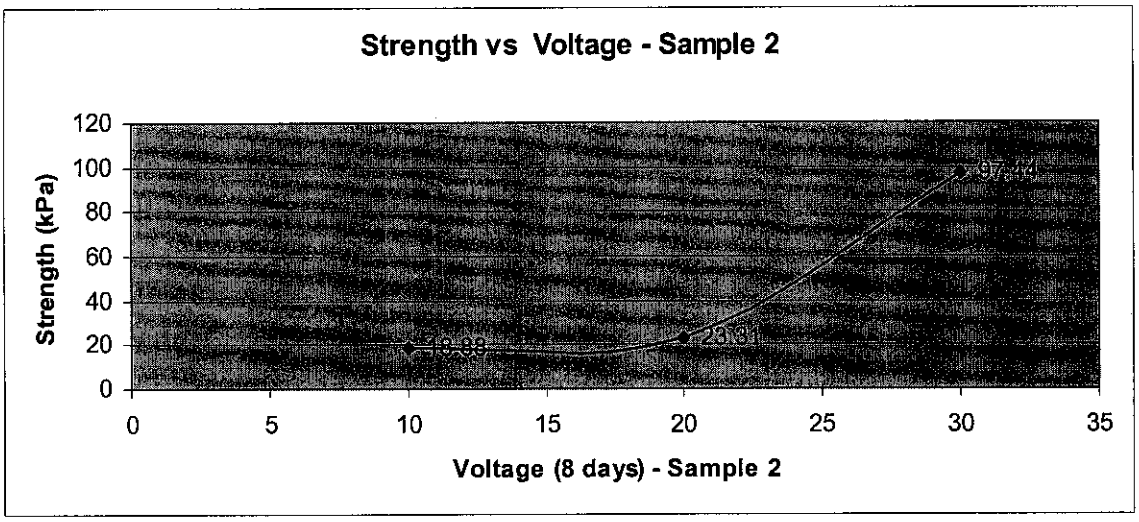

Figure 4.14: Strength versus Sample Location 2

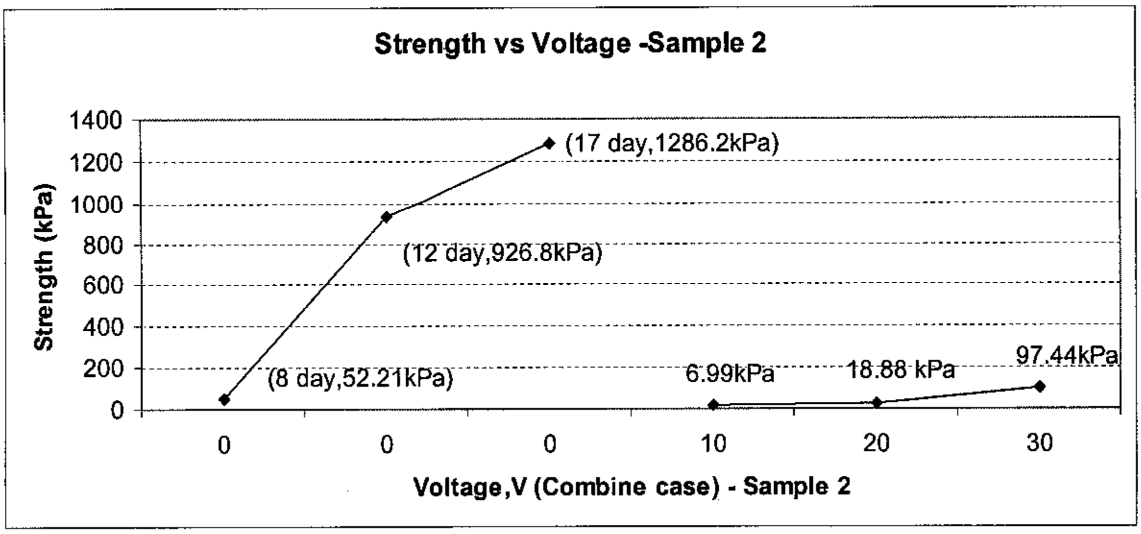

Figure 4.15: Comparison with/without Electrokinetic Sample Location 2

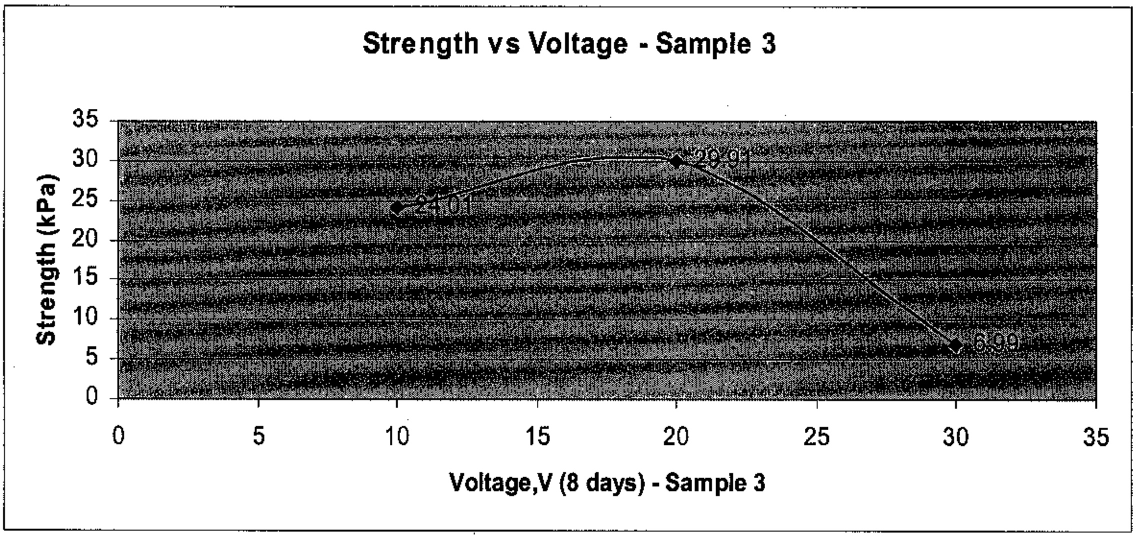

Figure 4.16: Strength versus Sample Location 3

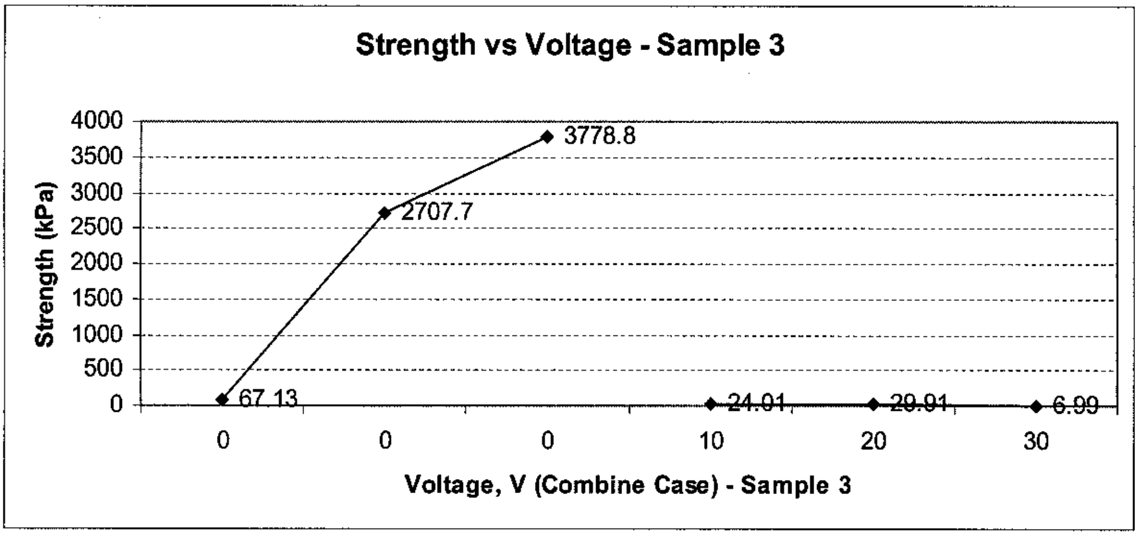

Figure 4.17: Comparison with/without Electrokinetic Sample Location 3

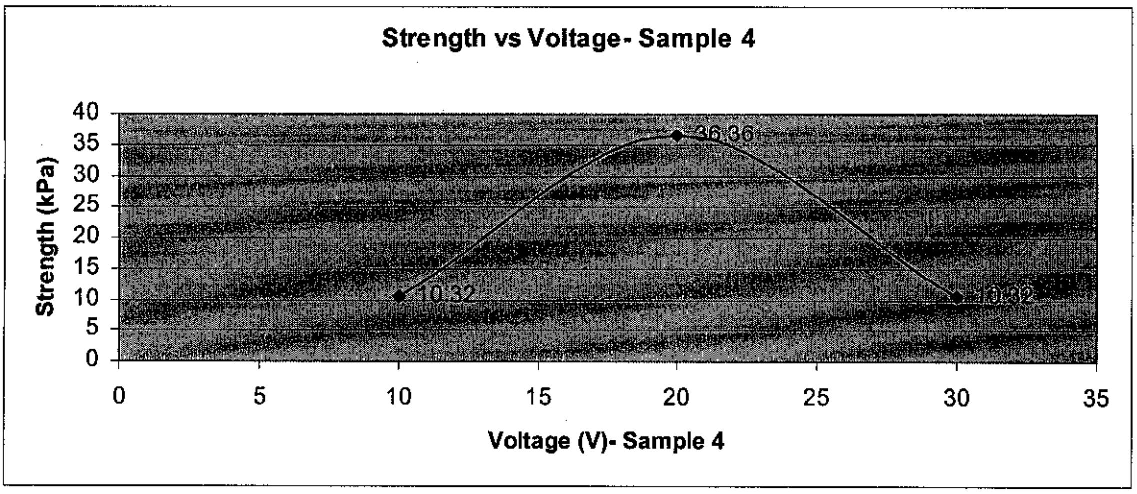

Figure 4.18: Strength versus Sample Location 4

4.2.4 Moisture Content

4.2.4.1 Experiment Without Electrokinetic

The weight of water regularly used for the testing is 2.8 kg with 5 kg of soil sample. As the soil sample mixed, water content was assumed remain the same. In this part of experiment, the kaolin slope was left for 8 day, 12 day and 17 days. The water used in the experiment is distilled water. The average moisture content of the sample was decreased gradually from the day eight (8 day) to day seventeen (17 day) (*See Figure 4.31*). The results of the this part of experiment comprises of the three identical graph for different respective days which are Figure 4.32, Figure 4.33 and Figure 4.34 each plotted on the same sample location taken along the slope. The analysis of data is measured from the bottom of the slope until the top of the slope. The different in its moisture is monitored thoroughly for comparison purposes. For every sample, the graph has been plotted from the bottom part until the top surface of the slope against the moisture content for each sample. The 8 days experiment showed that the highest moisture is on the top of the slope. It may be caused of the edge of the slope is not steep, so that the water flowing down so slowly and assemble at the top part of the soil which is presented in tray number 4. Therefore, the moisture content is higher than the bottom part. Hence, the capacity of water retain by the slope was reduced from the top to the base. While, the 12 days from Figure 4.33 showed that same patterns as for the 8 days but the percentage of moisture is a bit lower than the 8 days experiment. Again for the 17 days experiment, indicates the different trends of graph even though it shows that the higher percentage at the top but the bottom part almost higher than the medium layer of the soil.

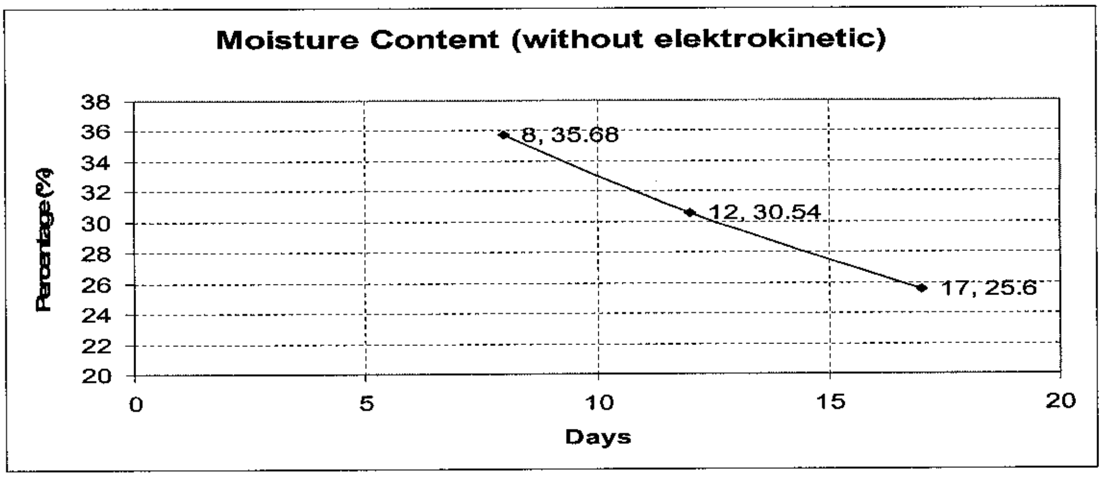

Figure 4.31: The Average of Moisture Content against the Respective Days

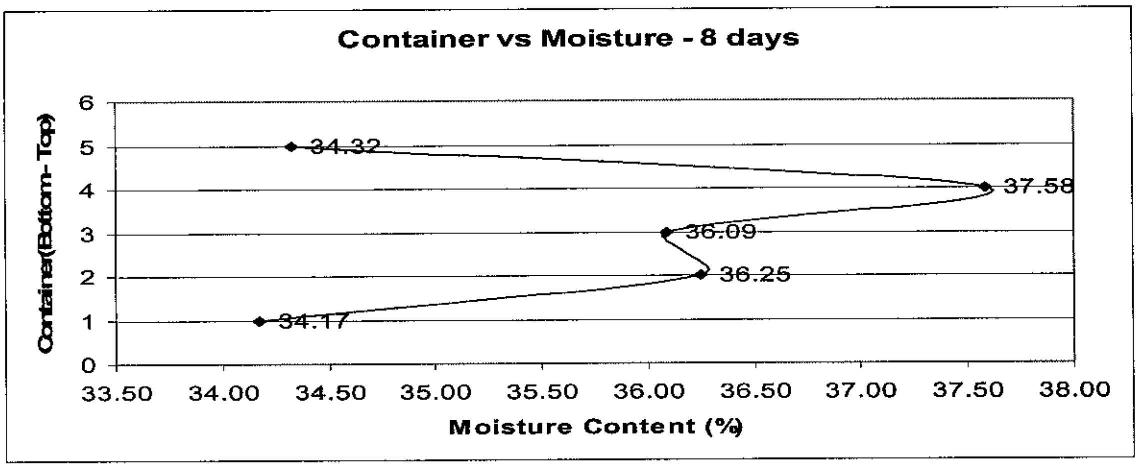

Figure 4.32: The Layers of the Sample against Moisture Content in 8 days

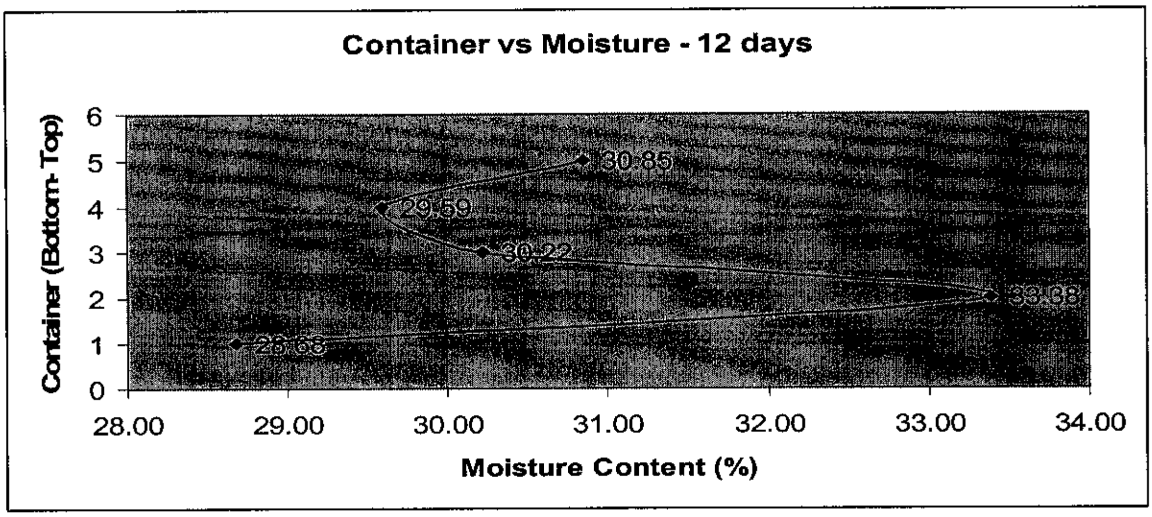

Figure 4.33: The Layers of the Sample against Moisture Content in 12 days

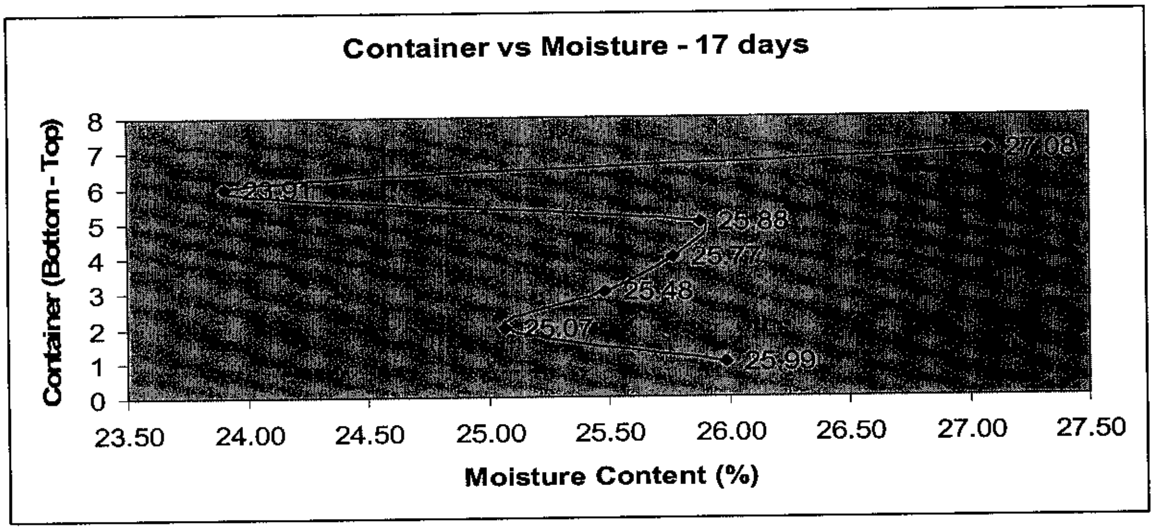

Figure 4.34: The Layers of the Sample against Moisture Content in 17 days

4.2.4.2 Experiment Using Electrokinetic

Another process of the experiment is used the electrokinetic technique which is the important part of the experiment. The movement of water in an electric field is known as electroosmosis. Other phenomena included the electrophoresis and ion migration. It is now realized that electroosmosis can now be improve the slope by controlling the moisture and the current applied. In this part, the DC power was supplied to the kaoline slope using the steel rods as cathodes and anodes which deliver current to the soil. The duration of the experiment taken is 8 days with different voltages. The voltages which have been used were 10 volt, 20 volt and 30 volt. The outcome of the experiment was achieved where four graphs which are Figure 4.35, Figure 4.36, Figure 4.37 and Figure 4.38 were plotted one for each voltage to the soil samples. Each sample was taken as Figure 4.10 shows the location of the samples on the slopes. From the analysis, the average moisture content increased 37.89% for the 10 volt test to the 41.74% for 30 volts test. Whereby, the sample varies of sample location also shows the increased of the moisture. For the 10 volt experiment, the moisture was increased from the location 1 until location 3. This is because of the excessively migration of water towards the cathodes which located in the middle of the slope. Therefore as discuss in the previous topic, the water ponding occurred around the cathodes. The observation of the process shown that water from the soil was flowed down through the holes in the middle of the basement box. This caused the small cracks on soil at the cathodes. It also found that the rods present the anodes have corroded under the oxidizing environment. The combine cases for the numbers of voltage applied was presented in Appendix 4-9 Figure 4.65 to Figure 4.69.

Moreover, the result obtained from the 20 volt and 30 volt analysis also showed higher percentage of the moisture content in the location 3. The flowing of water through the soil from anodes towards cathodes was increased proportional to the high voltage applied to the soil. The moisture in sample location 1 in the 10 volt is lower than the moisture in 20 volt and 30 volt. While, the percentage moist in sample location 2 for 10 volt is more than percentage moist in 20 and 30 volt. Furthermore, the higher moisture was found at the mid of the slope but the higher moisture content was found when the 10 volt applied to the slope. The reason why this happened is because of the appearance of the cracks in between the anodes and cathodes. When the higher voltage applied, it creates the cracks faster than the low voltage. The flows of waters were bordered from moving through the cracks. The graph analysis of every sample for each voltages shows in the Appendix 4-4 Figure 4.39 to Figure 4.47.

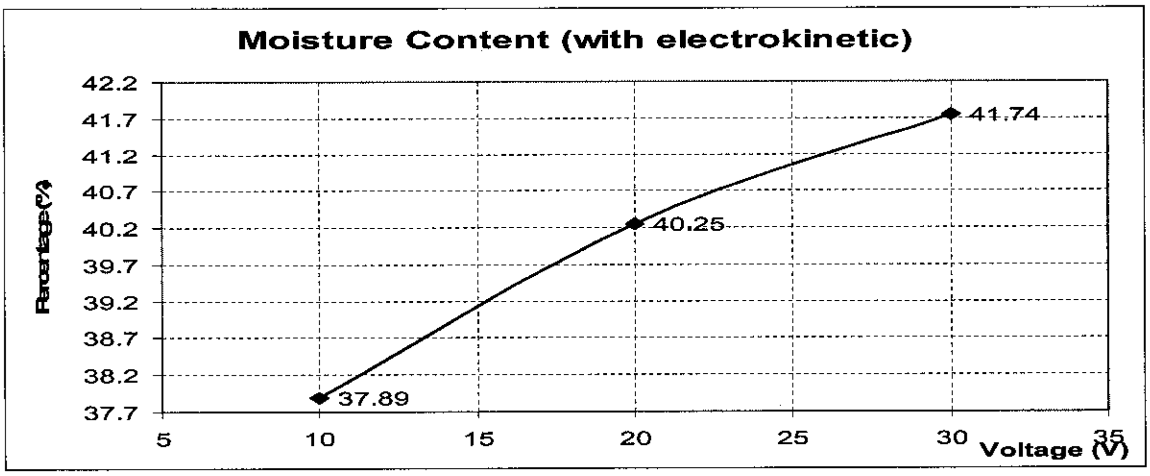

Figure 4.35: The average Moisture Content against the Voltage apply

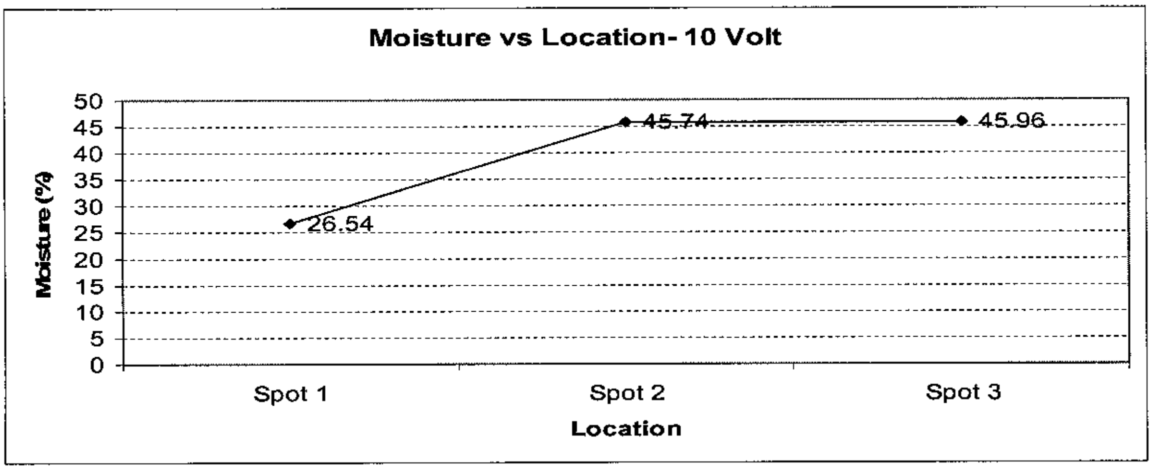

Figure 4.36: The Moisture Content against Sample Location for 10 Volt

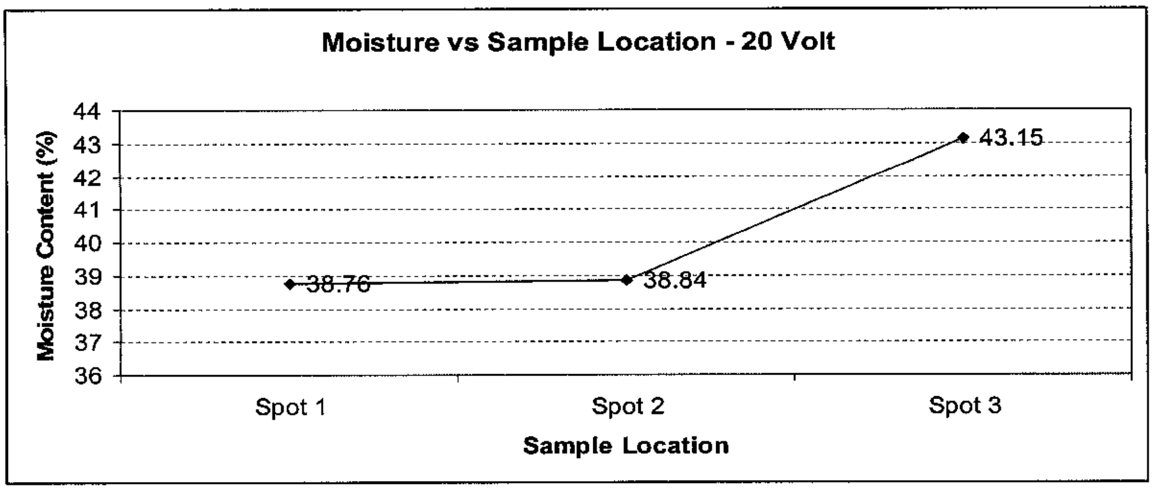

Figure 4.37: The Moisture Content against Sample Location for 20 Volt

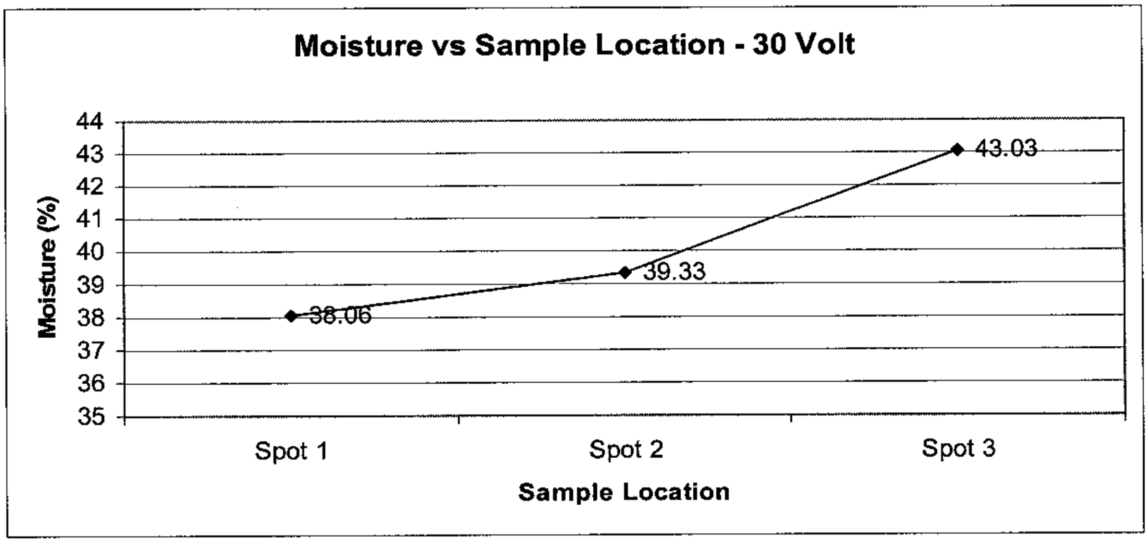

Figure 4.38: The Moisture Content against Sample Location for 30 Volt

4.2.5 The Current Flow

The voltage gradients across the soil sample during the electrokinetic processing were found to vary with time for all cases as shown in Appendix 4-5 Figure 4.49, Figure 4.50, Figure 4.51, Figure 4.52 and Figure 4.53. The table of the current during 8 days experiment was shown in Appendix 4-6 Table 4.8, Table 4.9 and Table 5.0.The changes of the voltage gradients in general were mainly because of changes of the resistivity of the soil probably increased due the formation of water by H^+ and OH^- within the soil sample or precipitation of hydroxides. The values of the voltage applied are from 10 volt to 30 volt. The current gradient decreased after the 170 hours of test. This is might be caused of the ionization of the certain compound in the kaolin soil as a result of the migration of cations from the anodes to the cathodes. The variations of the currents as illustrated in the Figure 4.53 were due to the combination of different voltage which applied to the soil slope. For all the testing, the migration of the ion towards cathodes were bordered because of the cracks occur at the middle of the slope. Therefore it slowed the movement of water and also effects the measurements of the current in the soil slope. From the observation, the cracks which appeared on the slopes were bigger when the 30 volt applied to the soil while the 10 volt only caused a small crack on the soil. Overall, the graph plotted shows, there are some deficiency during taken a readings because the current should be decreased for every hour but somehow the current start to fluctuate and decreases again until the end of the experiment. We also can assume that varies in the readings because of the cracks occurred in the experiments. The detail out of the graphs was presented in the Appendix 4-5 Figure 4.70 to Figure 4.81.

4.2.6 Comparison the Normal Arrangement of Anodes with the New Arrangement using 20 Volt

In this experiment, the arrangement of anodes was shown in the Appendix 4.7 Figure 4.48.The purpose of the testing is to make a comparison between the normal arrangement of the anodes and the new one in terms of the strength, moisture and the current in the soil sample. From the analysis, the new arrangements of the anodes contain high moisture contents compared to the normal arrangement. Although it has higher moisture contents, the percentage of the moisture keep decreasing from the sample location 1 through sample location 3. The locations for sampling are the same as shown in Figure 4.9. Theoretically, the sample location 3 should be the highest moisture content than the other two location, but the new arrangement of anodes gave the lower percentage than the sample location 1 and 2. The normal arrangement shows the correct percentage of the moisture content which higher moisture content in the sampling number 3. This phenomenon may be caused by the direction of the water and ions were changed towards the cathodes. The ponding phenomenon was observed in both cases as shown in Appendix 4-7 Figure 4.54, Figure 4.55, Figure 4.56 and Figure 4.57. From the graphs which in Appendix 4-8 Figure 4.62, the sample location 3 for the new arrangement of anodes was higher moisture at the top than the bottom of the soil. Meanwhile, the sample location 1 currently shown that the bottom of the soil contains more moisture than the top. Therefore, the different of the reading at the each location was probably present that the movement of the water is too slow or it also directs not only to the cathodes but to anodes itself. Using the normal arrangement of anodes, it was found that the sample location 3 gave the highest moisture content at the top of soil than it bottom. The movement of water was assumed goes directly to the cathodes and not to the anodes. Thus leaving the high percentage of moisture content in the soil around cathodes. The details were presented in graph in Appendix 4-8 Figure 4.58 to Figure 4.64 and also Table 4.11 and 4.12 for the data collection of the experiment.

Moreover, the strength of the soil with new arrangements was decreased gradually from sample location 1 to sample location 4 which refer to Appendix 4-8 Figure 4.63. It differs from the normal arrangement which increased it strength from sampling 1 until 4. But, it still gave the highest strength compared to the normal. Therefore, the new arrangement of the anodes should be better practices for further research using the different of voltage to the soil. Referring to the graph in Appendix 4-8 Figure 4.64, the currents for both cases keep decreasing through out the time taken. The fluctuation of current in certain time mostly because of the discrepancies of taken the reading using multimeter.

4. 3 PROBLEMS FACED AND RECOMMENDATIONS

4.3.1 Problem Faced

4.3.1.1 Early of the Project Study

In the early stage of the project, the intended project requirement is to fabricate the models of the Perspex box which fully represent the slopes at the site including the flow of water as a pore water pressure and also the other mechanical part of the models. However, regarding to the higher cost and time constraint, the adjustment of the design has to carry out to cut the time taken for fabrication. Therefore, the final design of the models to be fabricated is just a Perspex box with respective dimension and some critical part as per drawing in the previous discussion. As a result of the late in delivering, the fabrication can be done only in the semester two of the study period. Literature review and information gathering was done during the first semester of the research study. Regarding to the project topic, it was not easy to get the information on the Electrokinetic application on kaolinite slope because it is not widely done by researchers on that types of soil. Therefore putting great effort onto this project was only way to make the project realized. Fortunately, the project was successfully done within the time frame.

The models were fabricated in the semester two of the study period. Another problem faced was the error on cutting the Perspex by the foremen. They was failed to follow the drawing that was submitted to them. The completion of the fabrication was late due to the management of the workshop which past the job to other company to do the cutting. After negotiation was done the workshop successfully managed to complete the jobs.

4.3.1.2 Sample Preparation

Preparing the sample is the most important part in this experiment. The kaoiline soil was taken from the Bidor site and it was placed in the plastic bags until safely stored in the laboratory. The main elements to handle with the soil are to maintain the original moisture in the laboratory temperature. Some of the sample was not properly stored in the plastic bags and exposed to the air. The moisture of the soils was lost because of the tearing of the plastic bags. Another problem faced regarding to this matter was the long period of drying the soil in the oven. Therefore, some of the moist in the soil was fully removed.

4.3.1.3 Electrokinetic Experiment

The electrokinetic techniques have some parameters to control and monitor. The main problems are the placing of the rods into the holes provided at the top and base of the box. The miss-placed of the rods may cause short circuit of current in the circuit. This is because of the rods was touched the aluminum tray under the box. Furthermore, the experiment sets was not covered to avoid the extremely evaporate process of water from the soil sample. Regarding to the vane shear test experiment, the sample was sometimes was considered as disturbed sample because of the techniques when taking the sample using the casing. During the testing using vane shear apparatus, the sample was so sticky and slowly flows out from the casing. These may affect the reading of the vane penetration to the soil. As moisture content was concern

4.3.2 Recommendations

4.3.2.1 Project Management and Coordination

First of all, it is suggested that any project given to the student should be ensured the flexibility of the infrastructures and cost related to the project. Meaning to say, when the project is given for a particular person to study the entire expected requirement should be considered within the reachable scope. The availability of the equipments, software, apparatus and guidance will help the researchers a lot in producing a good paper. Difficulties in getting the tools and equipment will demoralize the researcher although the project is very interesting. Lack of communication and accountability should be avoided for better managerial, technical and capability building as guided in PETRONAS triple plus policy. With good communication, devices and tools availability and effort from the researcher, a good project will be produced even the best one could achieved. Close supervision is suggested but it is not compulsory as this is an independent project for the researcher before going to the real world of industries and research.

4.3.2.2 Project Improvement

The study of the stabilizing the kaolinite slope still has a lot of window of improvement and detailed research. There are many aspects and point of view that has not been studied for example the different types of rods rather than steel rod, the location of the anodes and cathodes on the slopes, the higher voltage than 10 volt, 20 volt and 30 volt, using surcharge at the top of slope and also the weight of water used during the mixing of the sample. Besides those identified criteria of improvement, there might be other point of view that the researcher has over looked. Some other researcher could have think in different way and looking forward to detail out the study better than what has been presented in this paper. All those kinds of efforts are highly welcomed to improve as well enhance the study that has been reported in the paper. This paper could be looked as a single step for a long journey with regards to the topic in research and development field for the benefit of human beings.

CHAPTER 5
CONCLUSION

Overall, this study is to determine the effect of electrokinetic method in stabilising the slope as well as finding the most effective method in electrokinetic stabilization. From the experiments and test that have been conducted through out the study period, it could be concluded that the application of electrokinetic in stabilizing the kaoilinite slope is proven to be effective. However, the further research has to be conducted to confirm that the technique is useful and applicable on site. The effectiveness of the technique depends on the amount of voltages used and also the orientation of cathodes and anodes on the slopes. As the voltage increases, the strength and the moisture contents of the kaoline soils also increase. It can be simplified that the strength is proportional to the voltage. When the moisture decrease, it means that the strength of the soils is bigger. Again, from the experiment and test that have been conducted through out the study period, it could be concluded that the Electrokinetic technique is proven to be effective in stabilizing the slope in terms of increasing it strength from the original condition. However, the variation of the strength and moisture content in the different location on the slope is hard to explain because of the unclear phenomenon inside the soil itself. Continuing decrease in the flow of current in the soil shows that the electrokinetic effect could go a long way in improving the stability and strengthening of kaolinite soil. The corrosion reaction also appeared in the cathodes because of the migration of ions.

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APPENDICES

APPENDIX 3-1

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Chartmoor Road, Chartwell Business Park, Leighton Buzzard, Bedfordshire LU7 8WG England
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ELE International

ELE INTERNATIONAL LTD

CALIBRATION CHART

SPRING SET FOR LAB VANE, 26-2275/10

SERIAL NO. 1103-10-1416

DATE. CALIBRATION VALID FROM DATE OF SALE

SIGNED.

CALIBRATION RESULTS — DEGREES DEFLECTION

TORQUE		SPRING No.			
Kg.cm	Nm	1	2	3	4
0.25	0.025	8	10	14	21
0.50	0.049	15	19	27	39
0.75	0.074	23	29	41	58
1.00	0.098	31	39	55	78
1.25	0.123	40	40	69	98
1.50	0.147	48	60	82	118
1.75	0.172	56	69	95	139
2.00	0.196	65	79	108	160
2.25	0.221	72	90	122	179
2.50	0.245	81	100	135	199
2.75	0.270	89	110	150	
3.00	0.295	98	120	161	
3.25	0.319	105	129	175	

IMPORTANT: KEEP THIS CHART WITH THE SET OF SPRINGS TO WHICH IT IS APPLICABLE - NOT THE APPARATUS.

A Vinder Instrumentation Company

Table 3.2: Calibration Chart for Vane Shear Test

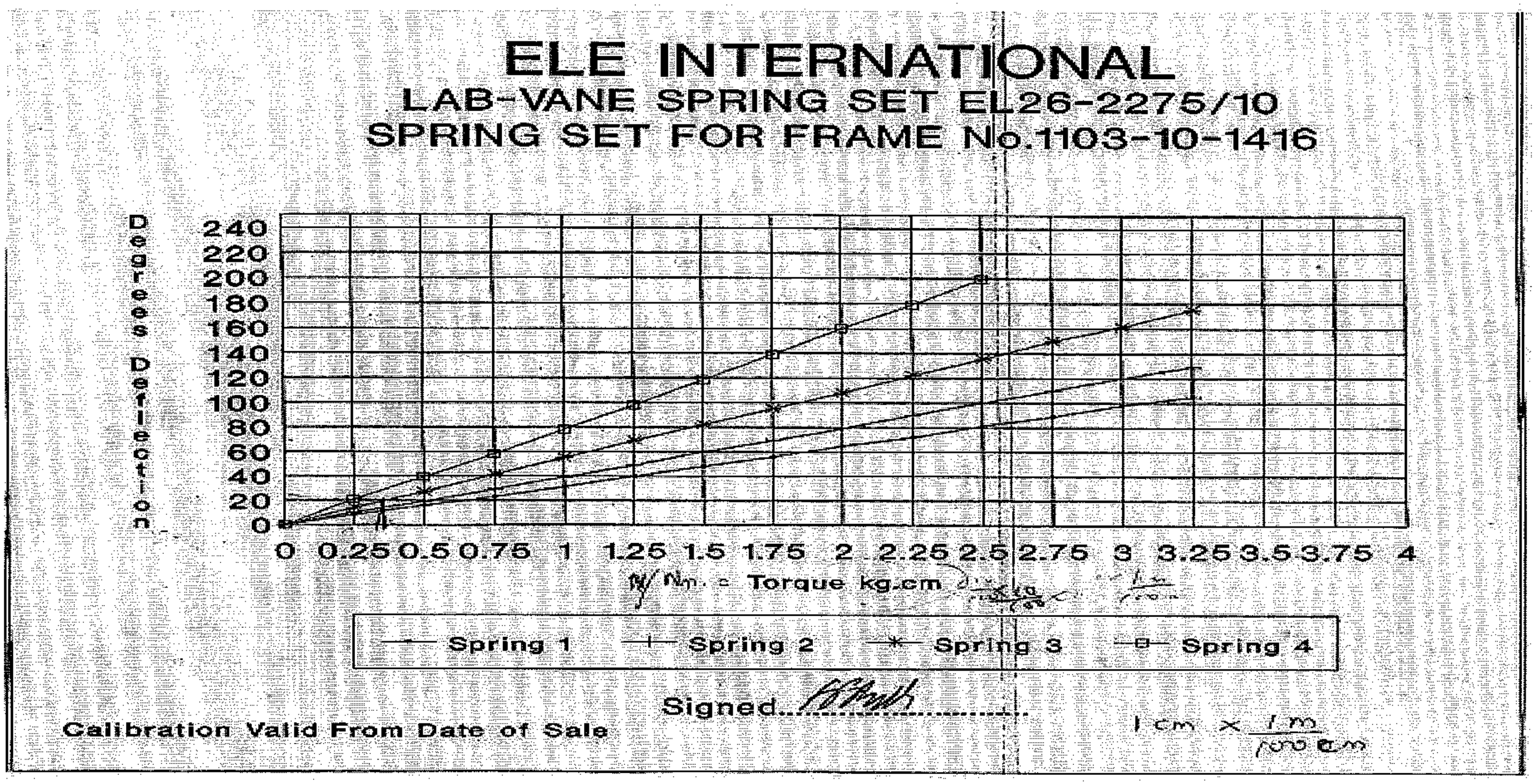


Figure 3.2: Lab- Vane Spring for Vane Shear Test

APPENDIX 4- 1

Vane Shear Test (With Electrokinetic)

Test 1: 10V

(Spot 1)
Deflection of spring = $\theta_f = 6^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 11^o

Torque, M = K x θ_f
= 0.005x 6^o
= 0.03Nmm = 30Nm

Vane Shear Strength = (M/4.29)
= (30/4.29)
= **6.99 kPa**

(Spot 2)

Deflection of spring = $\theta_f = 9^o$
Rotation of Vane = 9^o
Rotation of spring mounting = 18^o

Torque, M = K x θ_f
= 0.009 x 9^o
= 0.081 Nmm = 81Nm

Vane Shear Strength = (M/4.29)
= (81/4.29)
= **18.88 kPa**

(Spot 3)
Deflection of spring = $\theta_f = 10^o$
Rotation of Vane = 8^o
Rotation of spring mounting = 18^o

Torque, $M = K \times \theta_f$
$= 0.0103 \times 10^{o}$
$= 0.103$ Nmm $= 103$ Nm

Vane Shear Strength = (M/4.29)
= (103/4.29)
= **24.01 kPa**

(Spot 4)
Deflection of spring = $\theta_f = 7^{o}$
Rotation of Vane = 12^{o}
Rotation of spring mounting = 19^{o}

Torque, $M = K \times \theta_f$
$= 6.33 \times 10^{-3} \times 7^{o}$
$= 0.04431$ Nmm $= 44.31$ Nm

Vane Shear Strength = (M/4.29)
= (44.31/4.29)
= **10.32 kPa**

Test 2: 20 V

(Spot 1)
Deflection of spring = $\theta_f = 7^{o}$
Rotation of Vane = 20^{o}
Rotation of spring mounting = 27^{o}

Torque, $M = K \times \theta_f$
$= 6.33 \times 10^{-3} \times 7^{o}$
$= 0.04431$ Nmm $= 44.31$ Nm

Vane Shear Strength = (M/4.29)
= (44.31/4.29)
= **10.32 kPa**

(Spot 2)
Deflection of spring = $\theta_f = 10^o$
Rotation of Vane = 18^o
Rotation of spring mounting = 28^o

Torque, M = K x θ_f
= 0.01 x 10^o
= 0.1 Nmm = 100 Nm

Vane Shear Strength = (M/4.29)
= (100/4.29)
= **23.31 kPa**

(Spot 3)
Deflection of spring = $\theta_f = 11^o$
Rotation of Vane = 20^o
Rotation of spring mounting = 31^o

Torque, M = K x θ_f
= 0.012 x 11^o
= 0.128 Nmm = 128 Nm

Vane Shear Strength = (M/4.29)
= (128/4.29)
= **29.91 kPa**

(Spot 4)
Deflection of spring = $\theta_f = 13^o$
Rotation of Vane = 20^o
Rotation of spring mounting = 33^o

Torque, M = K x θ_f
= 0.012 x 13^o
= 0.156 Nmm = 156 Nm

Vane Shear Strength = (M/4.29)
= (156/4.29)
= **36.36 kPa**

Test 3: 30 V

(Spot 1)
Deflection of spring = $\theta_f = 9^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 14^o

Torque, M = K x θ_f
= 0.009 x 9^o
= 0.081 Nmm = 81 Nm

Vane Shear Strength = (M/4.29)
= (81/4.29)
= **18.88 kPa**

(Spot 2)
Deflection of spring = $\theta_f = 19^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 24^o

Torque, M = K x θ_f
= 0.022 x 19^o
= 0.418 Nmm = 418 Nm

Vane Shear Strength = (M/4.29)
= (418/4.29)
= **97.44 kPa**

(Spot 3)
Deflection of spring = $\theta_f = 6^o$
Rotation of Vane = 1^o
Rotation of spring mounting = 7^o

Torque, M = K x θ_f
= 0.005 x 6^o
= 0.03 Nmm = 30 Nm

Vane Shear Strength = (M/4.29)
= (30/4.29)
= **6.99 kPa**

(Spot 4)
Deflection of spring = $\theta_f = 7^\circ$
Rotation of Vane = 5°
Rotation of spring mounting = 12°

Torque, $M = K \times \theta_f$
$= 6.33 \times 10^{-3} \times 7^\circ$
$= 0.04431$ Nmm = 44.31 Nm

Vane Shear Strength = (M/4.29)
= (43.31/4.29)
= **10.32 kPa**

(Spot 5)
Deflection of spring = $\theta_f = 14^\circ$
Rotation of Vane = 5°
Rotation of spring mounting = 19°

Torque, $M = K \times \theta_f$
$= 0.016 \times 14^\circ$
$= 0.224$ Nmm = 224 Nm

Vane Shear Strength = (M/4.29)
= (224/4.29)
= **52.21 kPa**

Test 4: 20 V (diff orient.)

(Spot 1)
Deflection of spring = θ_f = 13°
Rotation of Vane = 5°
Rotation of spring mounting = 18°

Torque, M = K x θ_f
= 0.012 x 13°
= 0.156 Nmm = 156 Nm

Vane Shear Strength = (M/4.29)
= (156/4.29)
= **36.36 kPa**

(Spot 2)
Deflection of spring = θ_f = 10°
Rotation of Vane = 1°
Rotation of spring mounting = 11°

Torque, M = K x θ_f
= 0.01 x 10°
= 0.1 Nmm = 100 Nm

Vane Shear Strength = (M/4.29)
= (100/4.29)
= **23.31 kPa**

(Spot 3)
Deflection of spring = θ_f = 8°
Rotation of Vane = 5°
Rotation of spring mounting = 13°

Torque, M = K x θ_f
= 0.008 x 8°
= 0.064 Nmm = 64 Nm

Vane Shear Strength = (M/4.29)
= (64/4.29)
= **14.92 kPa**

(Spot 4)
Deflection of spring = $\theta_f = 8^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 13^o

Torque, M = K x θ_f
= 0.008 x 8^o
= 0.064 Nmm = 64 Nm

Vane Shear Strength = (M/4.29)
= (64/4.29)
= **14.92 kPa**

Average:

Test 1: 15.05 kPa

Test 2: 22.22 kPa

Test 3: 37.17 kPa

Test 4: 22.38 kPa

Vane Shear Test (Without Electrokinetic)

Test 1: 17 day

(Spot 1)
Deflection of spring = $\theta_f = 96^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 101^o

Torque, M = K x θ_f
= 0.121 x 96^o
= 11.616 Nmm = 11616 Nm

Vane Shear Strength = (M/4.29)
= (11616/4.29)
= **2707.7 kPa**

(Spot 2)
Deflection of spring = $\theta_f = 66^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 71^o

Torque, M = K x θ_f
= 0.0836 x 66^o
= 5.518 Nmm = 5518 Nm

Vane Shear Strength = (M/4.29)
= (5518/4.29)
= **1286.2 kPa**

(Spot 3)
Deflection of spring = $\theta_f = 114^o$
Rotation of Vane = 5^o
Rotation of spring mounting = 119^o

Torque, M = K x θ_f
= 0.1422 x 114^o
= 16.211 Nmm = 16211 Nm

Vane Shear Strength = (M/4.29)
= (16211/4.29)
= **3778.8 kPa**

Test 2: 8 day

(Spot 1)
Deflection of spring = θ_f = 12°
Rotation of Vane = 1°
Rotation of spring mounting = 13°

Torque, M = K x θ_f
= 0.013 x 12°
= 0.156 Nmm = 156 Nm

Vane Shear Strength = (M/4.29)
= (156/4.29)
= **36.36 kPa**

(Spot 2)
Deflection of spring = θ_f = 14°
Rotation of Vane = 5°
Rotation of spring mounting = 19°

Torque, M = K x θ_f
=0.016 x 14°
= 0.224 Nmm = 224 Nm

Vane Shear Strength = (M/4.29)
= (224/4.29)
= **52.21 kPa**

(Spot 3)
Deflection of spring = θ_f = 16°
Rotation of Vane = 0°
Rotation of spring mounting = 16°

Torque, M = K x θ_f
= 0.018 x 16°
= 0.288 Nmm = 288 Nm

Vane Shear Strength = (M/4.29)
= (288/4.29)
= **67.13 kPa**

Test 3: 12 day

(Spot 1)
Deflection of spring = θ_f = 88°
Rotation of Vane = 3°
Rotation of spring mounting = 91°

Torque, M = K x θ_f
= 0.111 x 88°
= 9.768 Nmm = 9768 nm

Vane Shear Strength = (M/4.29)
= (9768/4.29)
= **2276.9 kPa**

(Spot 2)
Deflection of spring = θ_f = 56°
Rotation of Vane = 5°
Rotation of spring mounting = 61°

Torque, $M = K \times \theta_f$
$= 0.071 \times 56^{o}$
$= 3.976$ Nmm = 3976 Nm

Vane Shear Strength = (M/4.29)
= (3976/4.29)
= **926.8 kPa**

(Spot 3)
Deflection of spring = $\theta_f = 96^{o}$
Rotation of Vane = 5^{o}
Rotation of spring mounting = 101^{o}

Torque, $M = K \times \theta_f$
$= 0.121 \times 96^{o}$
$= 11.616$ Nmm = 11616 Nm

Vane Shear Strength = (M/4.29)
= (11616/4.29)
= **2707.7 kPa**

Average:

Test 1: 2590.9 kPa = 17 day

Test 3: 1970.5 kPa = 12 day

Test 2: 51.90 kPa = 8 day

APPENDIX 4-2

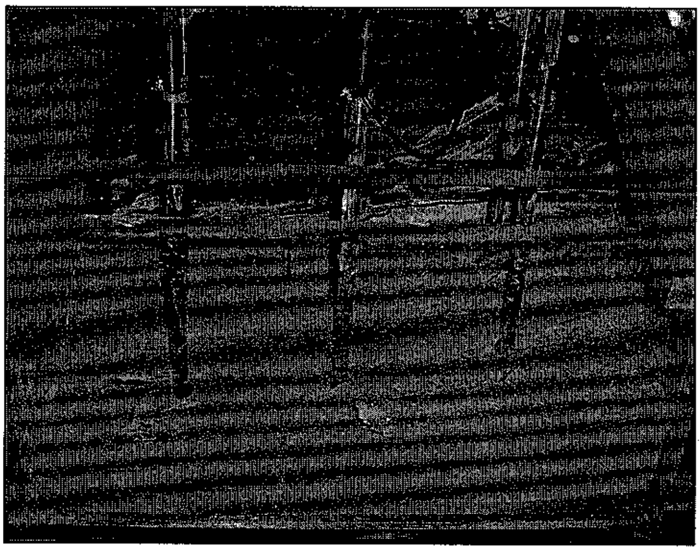


Figure 4.19: Cracks appeared using 30 volt

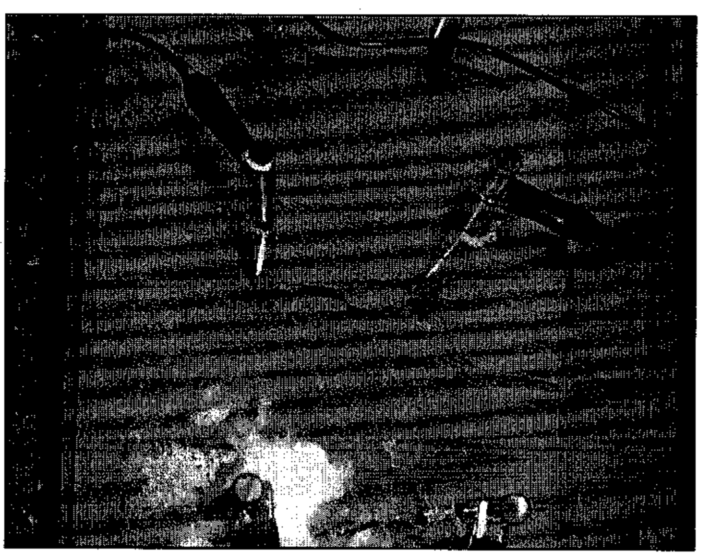


Figure 4.20: Cracks appeared in the middle of Slope

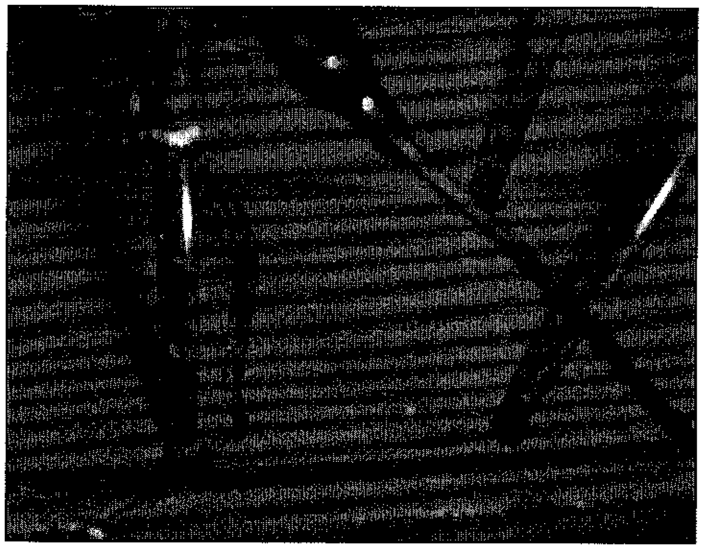


Figure 4.21: Cracks near the Cathodes

Figure 4.22: Cracks appeared in the middle of Slope

APPENDIX 4-3

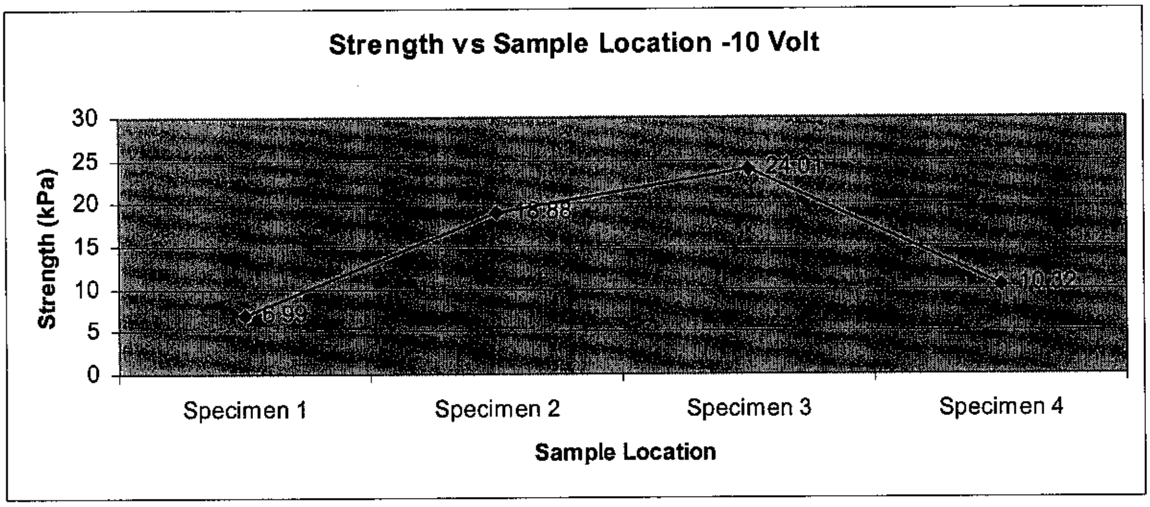


Figure 4.23: Strength against Sample Location for 10 Volt

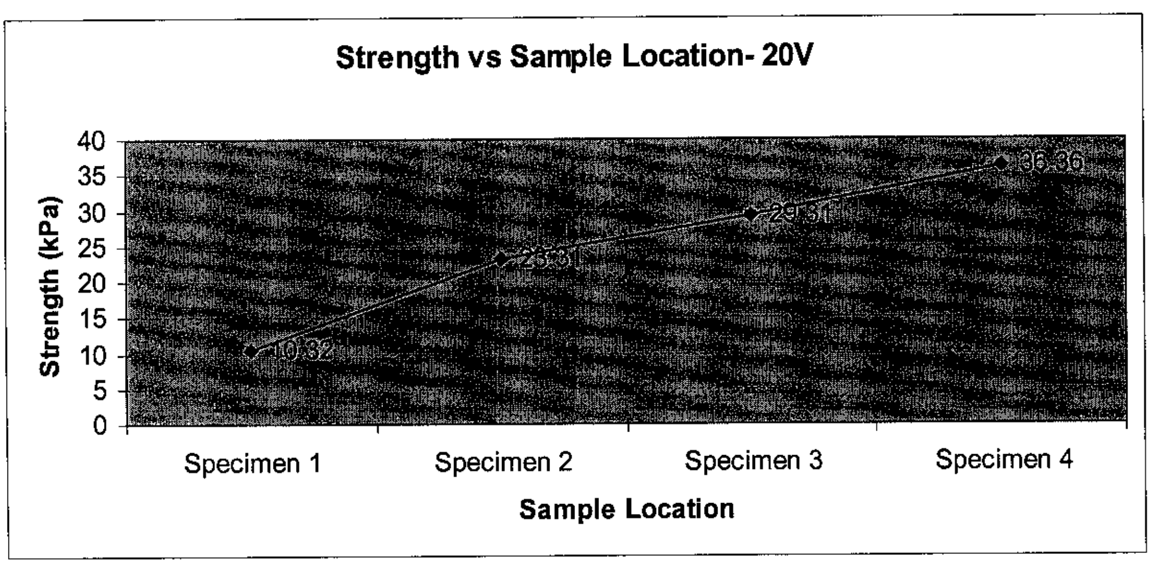


Figure 4.24: Strength against Sample Location for 20 Volt

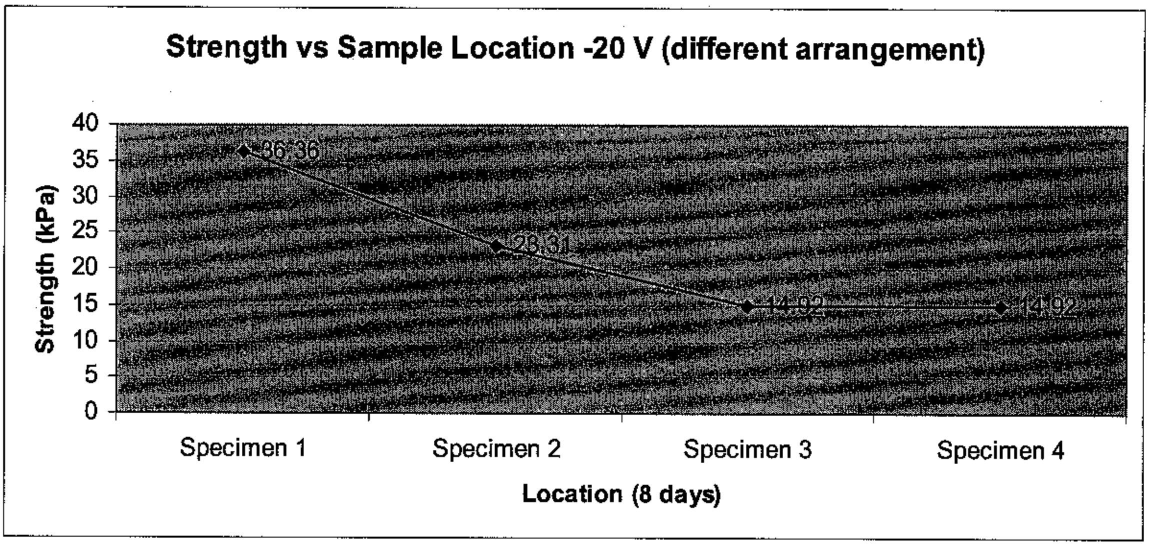


Figure 4.25: Strength against Sample Location for 20 Volt (Different arrangement)

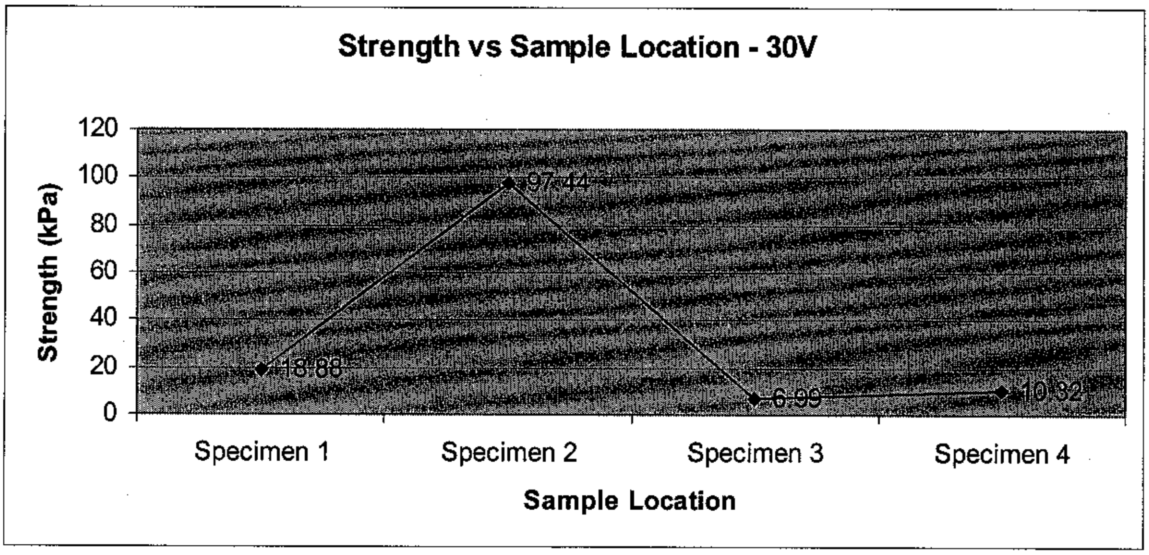


Figure 4.26: Strength against Sample Location for 30 Volt

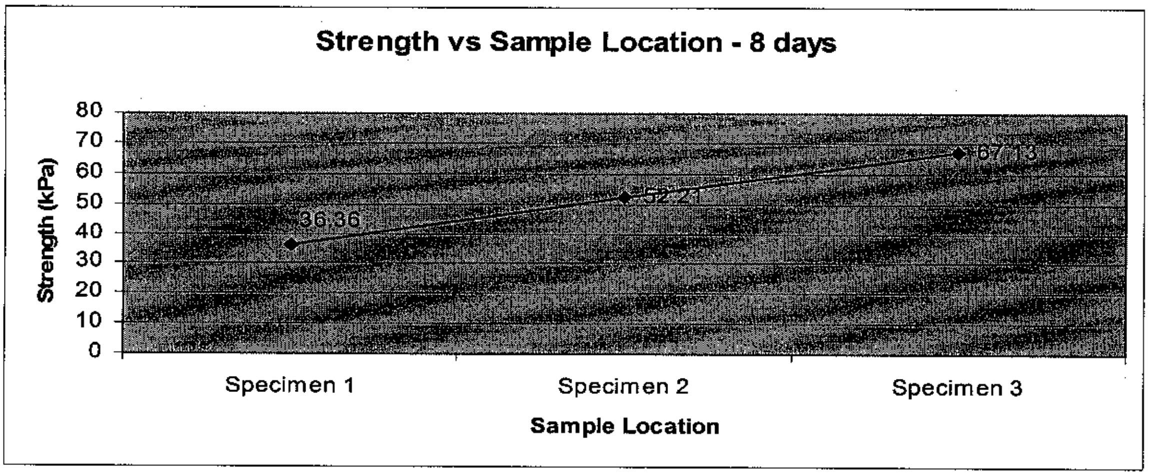


Figure 4.27: Strength against Sample Location for 8 days

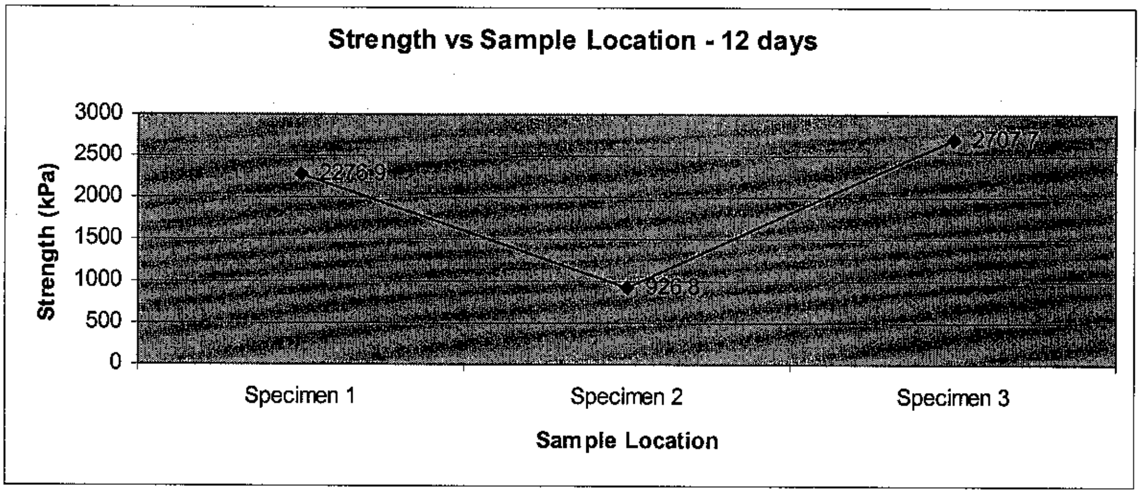


Figure 4.28: Strength against Sample Location for 12 days

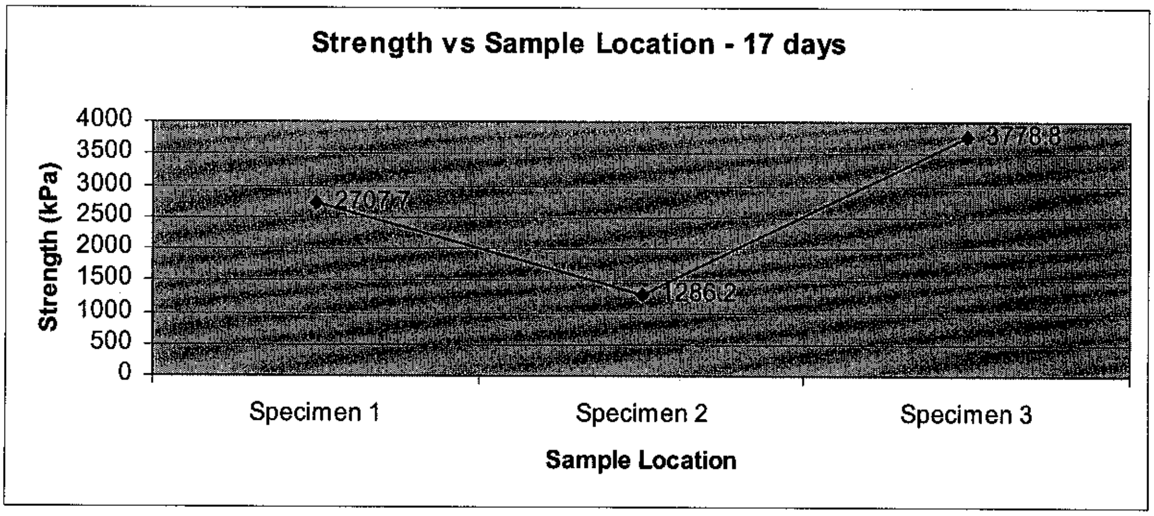


Figure 4.29: Strength against Sample Location for 17 days

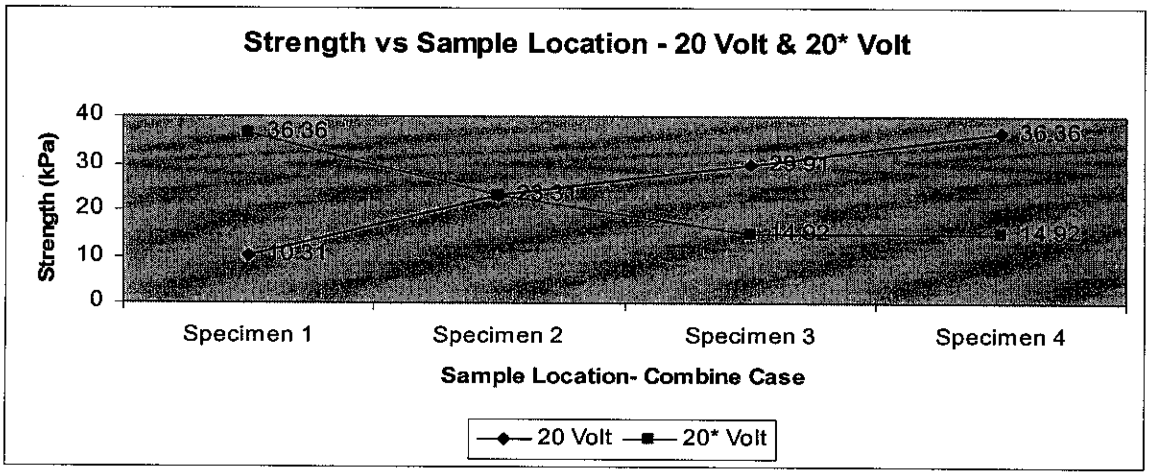


Figure 4.30: Comparison between 20 volt with normal and different arrangement

APPENDIX 4-4

Test 1: 10 Volt

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	19.44	43.96	39.68	4.28	20.24	21.15
2	19.75	44.8	40.07	4.73	20.32	23.28
3	19.55	50.97	44.13	6.84	24.58	27.82
4	19.58	56.69	48.13	8.56	28.55	29.98
5	19.53	59.07	49.84	9.23	30.31	30.45
					Average	26.54

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	19.47	37.99	31.82	6.17	12.35	49.95
2	19.74	38.08	32.44	5.64	12.7	44.41
3	19.54	39.93	33.62	6.31	14.08	44.82
4	19.58	40.67	34.04	6.63	14.46	45.85
5	19.53	44	36.56	7.44	17.03	43.68
					Average	45.74

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	19.46	35.32	30.55	4.77	11.09	43.01
2	19.73	35	30.23	4.77	10.5	45.43
3	19.53	35.82	30.61	5.21	11.08	47.02
4	19.57	35.62	30.51	5.11	10.94	46.71
5	19.52	40.56	33.77	6.79	14.25	47.65
					Average	45.96

Table 4.2: Table of Moisture Content for 10 Volt

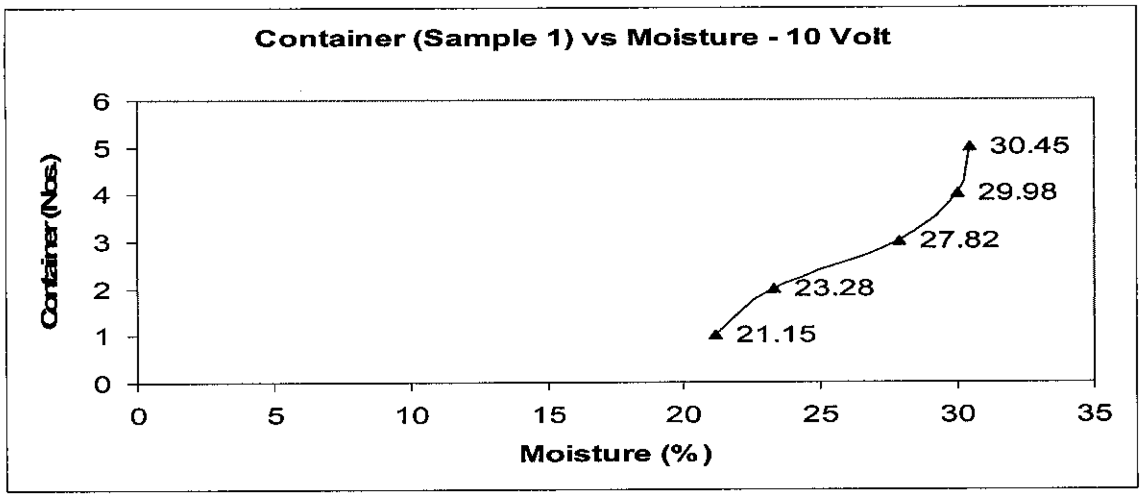


Figure 4.39: Layer of the sample 1 against Moisture for 10 volt

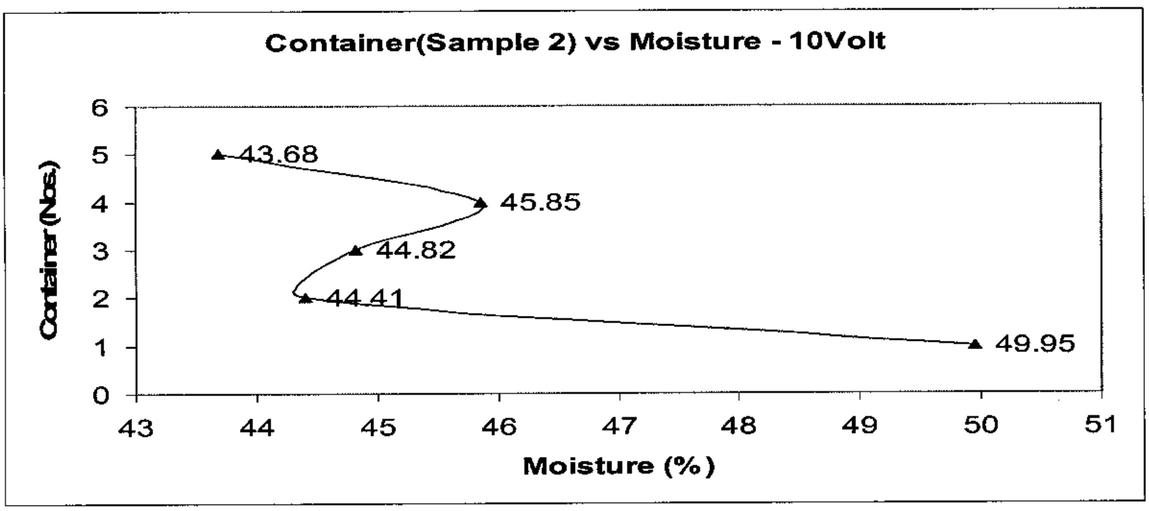


Figure 4.40: Layer of the sample 2 against Moisture for 10 volt

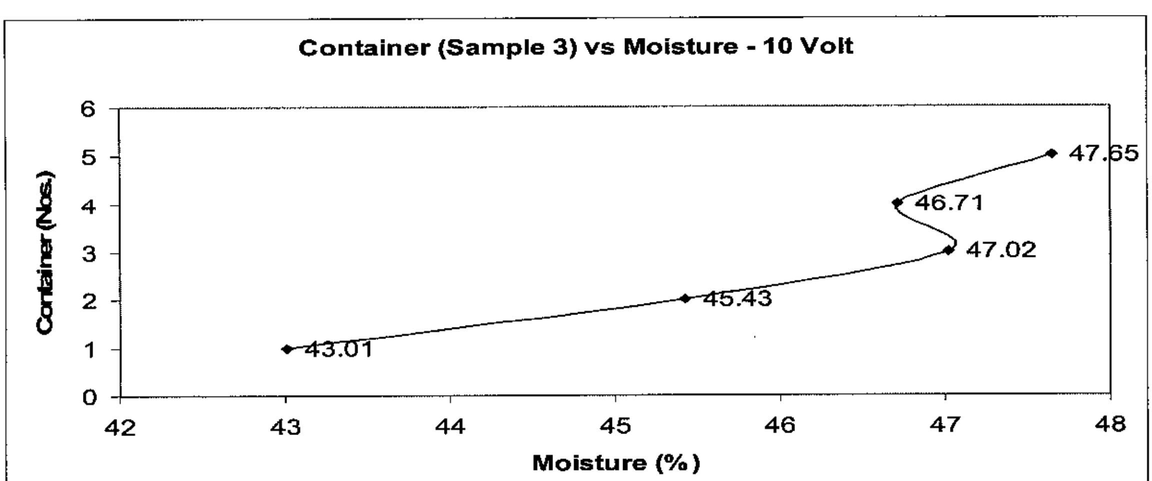


Figure 4.41: Layer of the sample 3 against Moisture for 10 volt

Test 2: 20 Volt

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	28.14	42.2	38.24	3.96	10.1	39.21
2	28.35	41.28	37.68	3.6	9.33	38.59
3	28.13	41.96	38.13	3.83	10	38.30
4	28.26	42.21	38.27	3.94	10.01	39.36
5	36.09	56.15	50.59	5.56	14.5	38.34
					Average	38.76

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	18.72	30.33	27.12	3.21	8.4	38.21
2	18.66	29.75	26.67	3.08	8.01	38.45
3	18.64	30.05	26.86	3.19	8.22	38.81
4	18.54	29.11	26.23	2.88	7.69	37.45
5	18.67	39.35	33.31	6.04	14.64	41.26
					Average	38.84

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	18.46	38.4	32.49	5.91	14.03	42.12
2	18.63	38.42	32.43	5.99	13.8	43.41
3	18.37	38.63	32.48	6.15	14.11	43.59
4	18.5	42.87	35.51	7.36	17.01	43.27
5	18.37	38.91	32.7	6.21	14.33	43.34
					Average	43.15

Table 4.3: Table of Moisture Content for 20 Volt

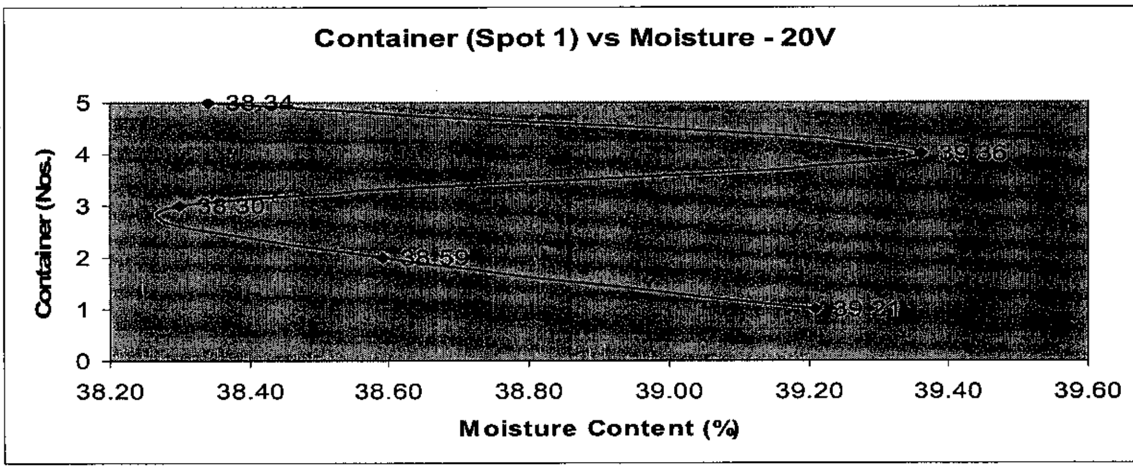


Figure 4.42: Layer of the sample 1 against Moisture for 20 volt

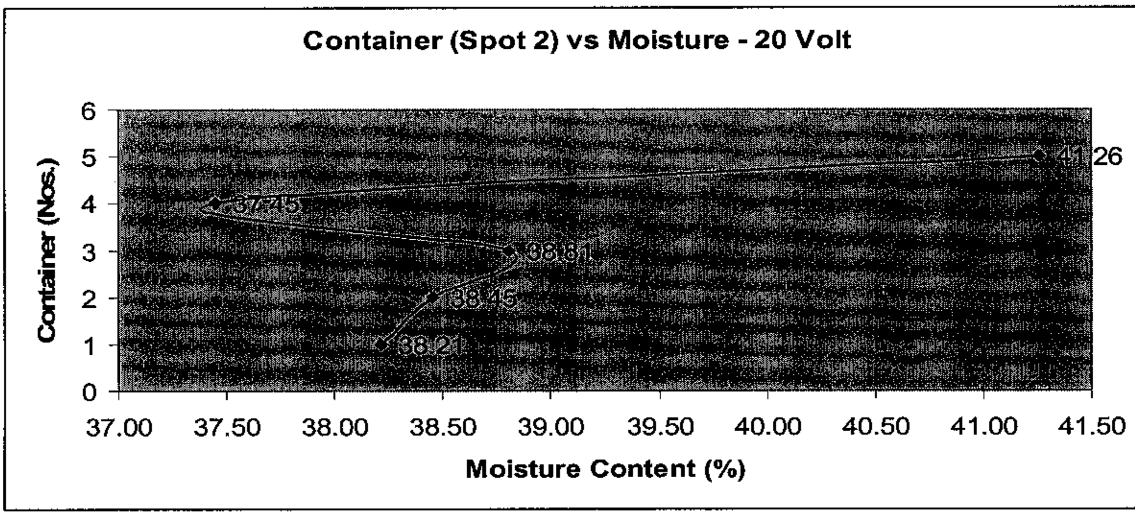


Figure 4.43: Layer of the sample 2 against Moisture for 20 volt

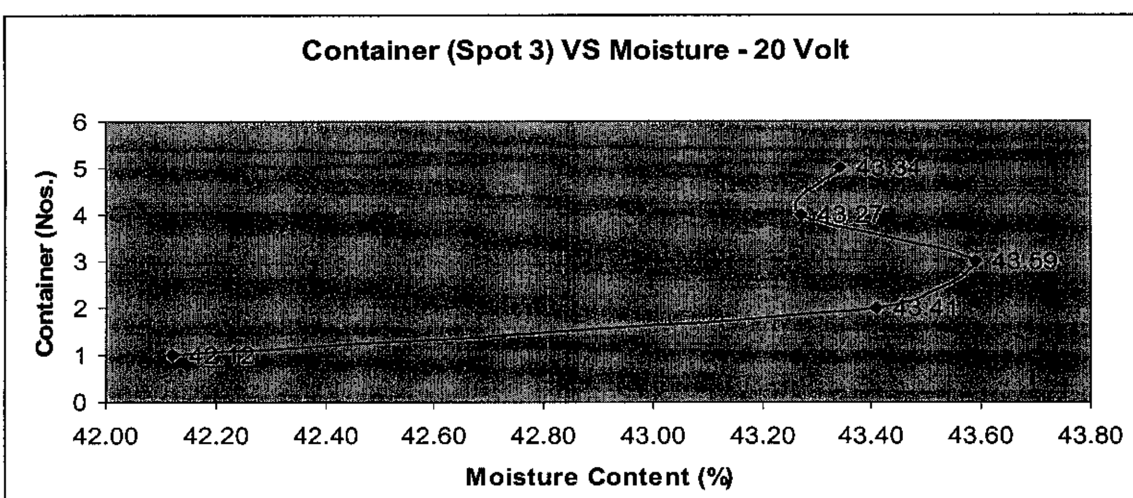


Figure 4.44: Layer of the sample 3 against Moisture for 20 volt

Test 3: 30 Volt

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	29.16	48.56	43.6	4.96	14.44	34.35
2	29.37	43.47	39.51	3.96	10.14	39.05
3	29.14	44.03	39.81	4.22	10.67	39.55
4	29.25	46.56	41.71	4.85	12.46	38.92
5	37.78	53.14	48.32	4.82	12.54	38.44
					Average	38.06

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	19.63	41.65	35.57	6.08	15.94	38.14
2	19.54	33.76	29.64	4.12	10.1	40.79
3	19.47	30.33	27.21	3.12	7.74	40.31
4	19.47	35.19	30.85	4.34	11.34	38.27
5	19.53	32.5	28.85	3.65	9.32	39.16
					Average	39.33

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	19.71	41.13	34.79	6.34	15.08	42.04
2	19.66	40.88	34.54	6.34	14.88	42.61
3	19.62	41.23	34.76	6.47	15.14	42.73
4	19.54	41.93	35.1	6.83	15.56	43.89
5	19.72	38.9	33.05	5.85	13.33	43.89
					Average	43.03

Table 4.4: Table of Moisture Content for 30 Volt

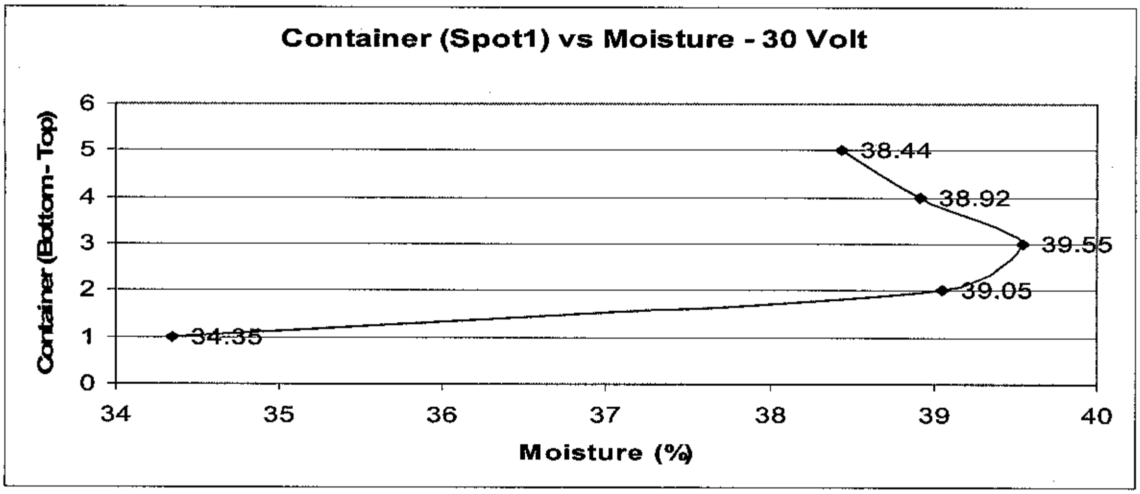


Figure 4.45: Layer of the sample 1 against Moisture for 30 volt

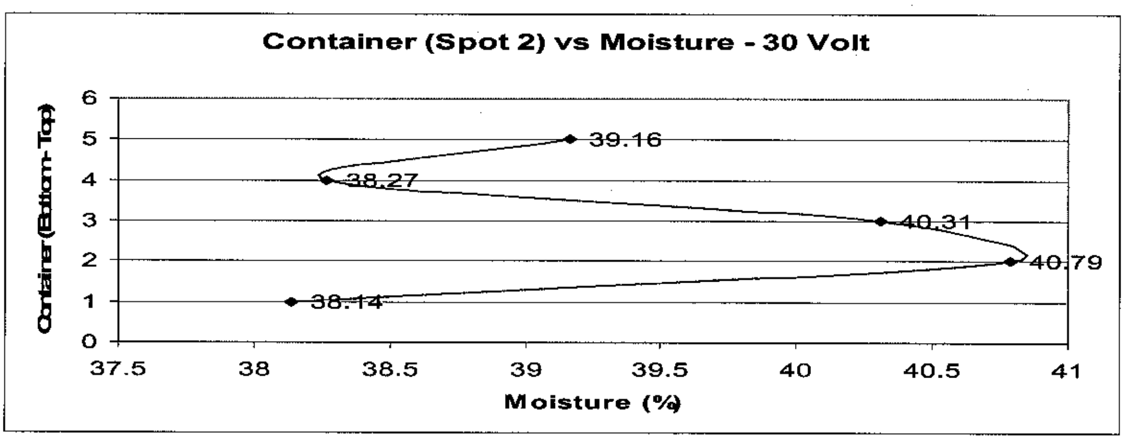


Figure 4.46: Layer of the sample 2 against Moisture for 30 volt

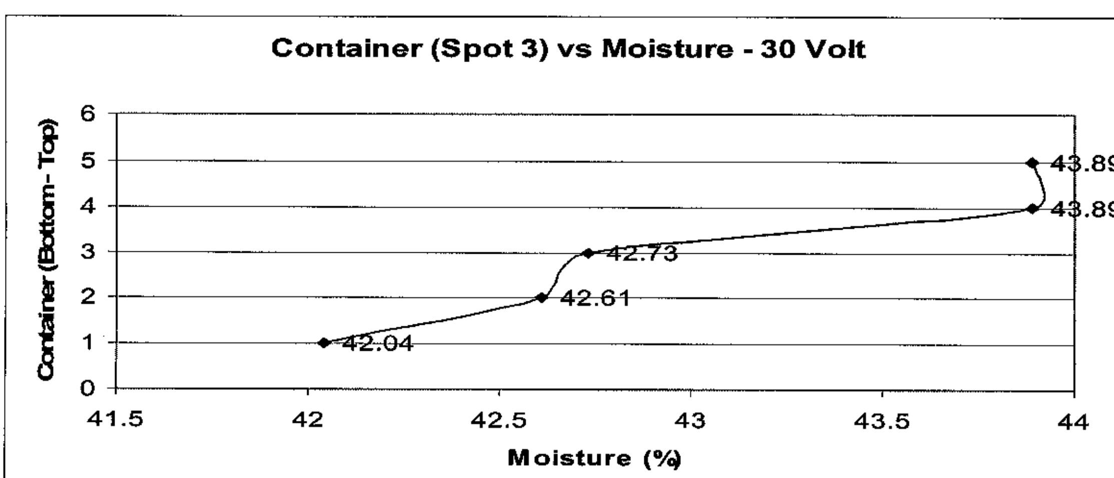


Figure 4.47: Layer of the sample 3 against Moisture for 30 volt

Test 4: 8 Days

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	19.62	43.14	37.15	5.99	17.53	34.17
2	19.53	41.18	35.42	5.76	15.89	36.25
3	19.45	42.19	36.16	6.03	16.71	36.09
4	19.45	39.66	34.14	5.52	14.69	37.58
5	19.52	44.41	38.05	6.36	18.53	34.32
					Average	35.68

Table 4.5: Table of Moisture Content for 8 days

Test 5: 12 day

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	29.14	79.88	61.23	18.65	32.09	58.12
2	29.31	88.26	65.28	22.98	35.97	63.89
3	29.11	73.36	56.26	17.1	27.15	62.98
4	29.28	65.39	51.3	14.09	22.02	63.98
					Average	62.24

Table 4.6: Table of Moisture Content for 12 days

Test 6: 17 day

Container	m_1	m_2	m_3	$(m_2 - m_3)$	$(m_3 - m_1)$	%
1	29.15	42.39	36.31	6.08	7.16	84.92
2	29.28	43.88	37.37	6.51	8.09	80.47
3	29.14	44.79	37.99	6.8	8.85	76.84
4	29.3	47.83	40.31	7.52	11.01	68.30
5	29.81	49.89	41.93	7.96	12.12	65.68
					Average	75.24

Table 4.7: Table of Moisture Content for 17 days

APPENDIX 4-5

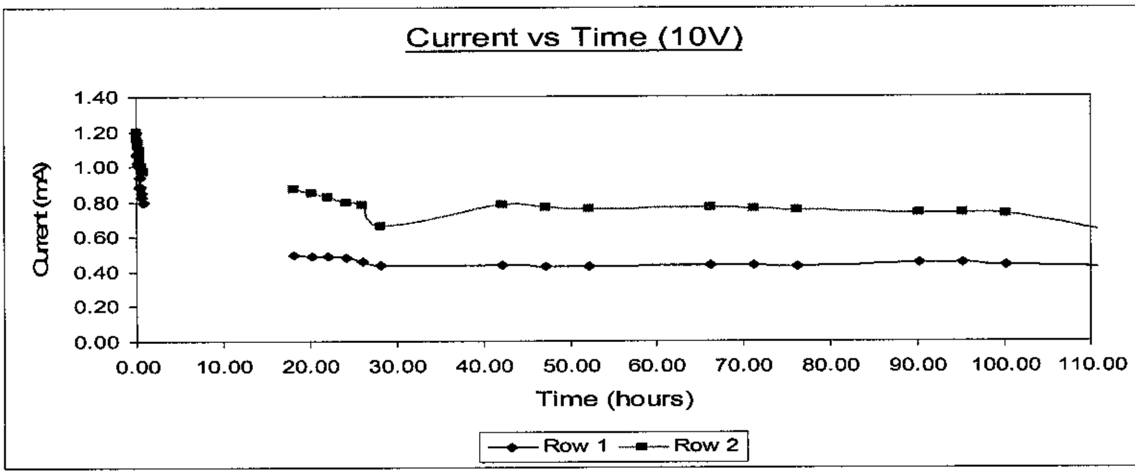


Figure 4.49: Current applied versus Time for 10 Volt

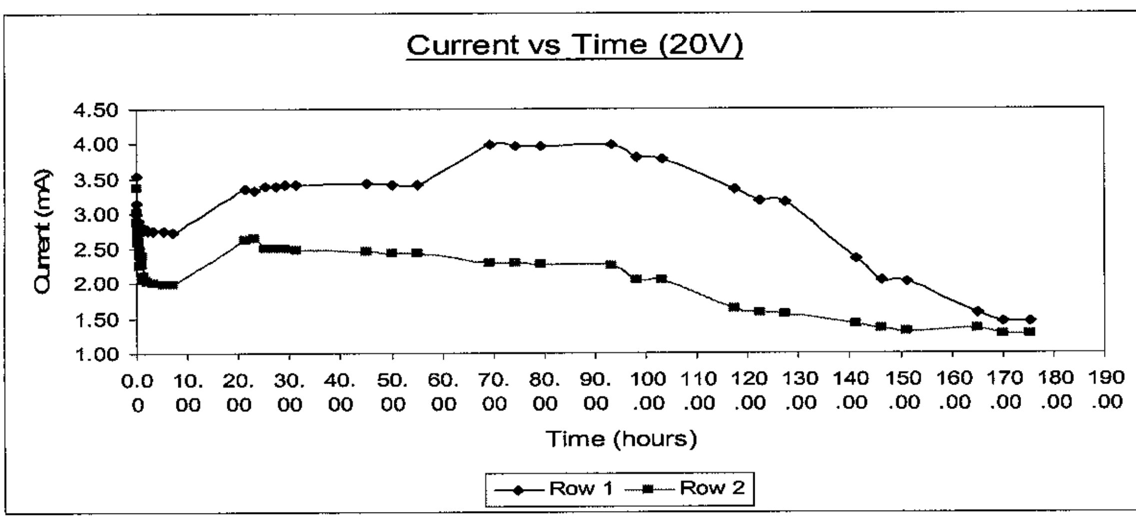


Figure 4.50: Current applied versus Time for 20 Volt

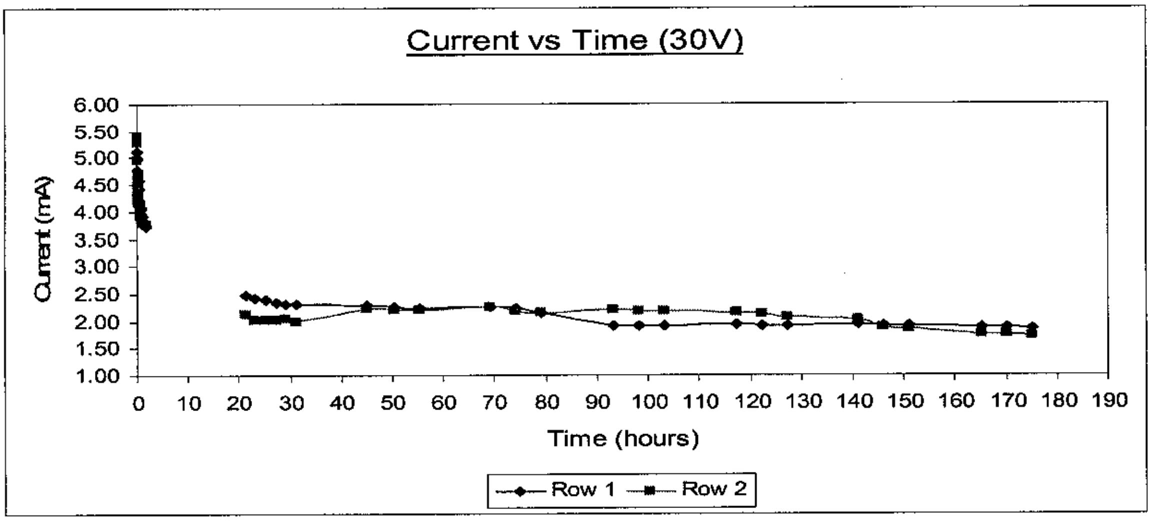


Figure 4.51: Current applied versus Time for 30 Volt

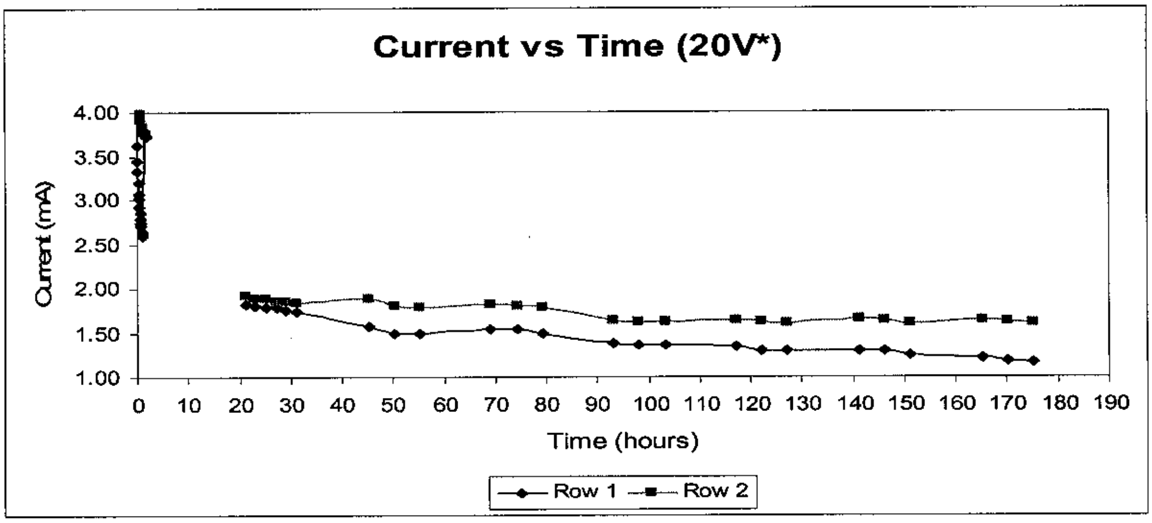


Figure 4.52: Current applied versus Time for 20 Volt (Different arrangement)

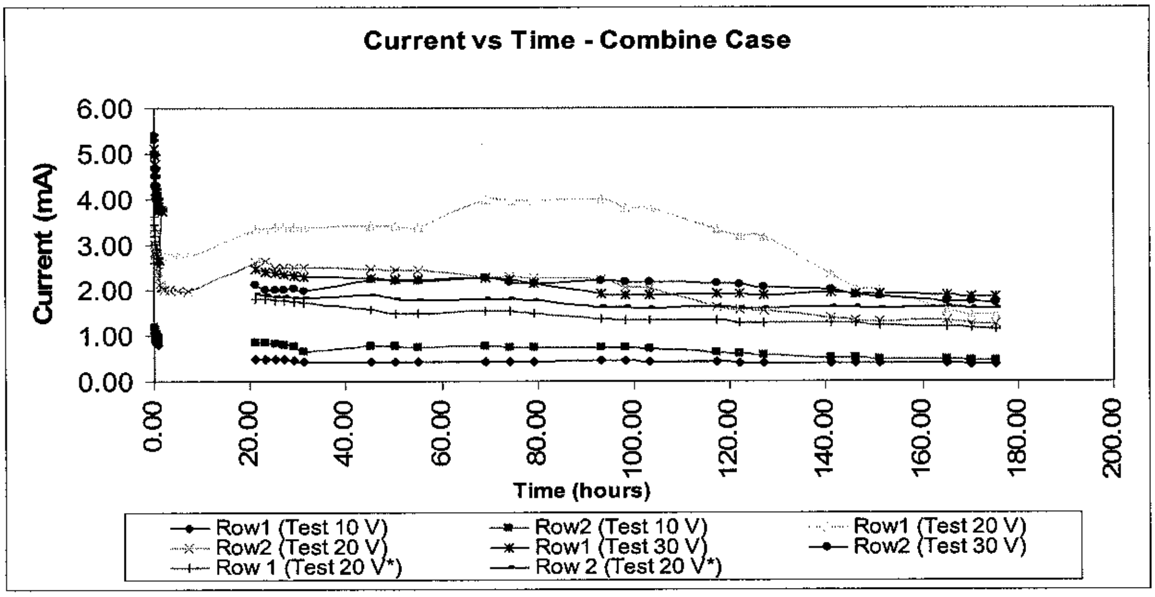


Figure 4.53: Combination of the Varies Voltage on the Sample

APPENDIX 4-5

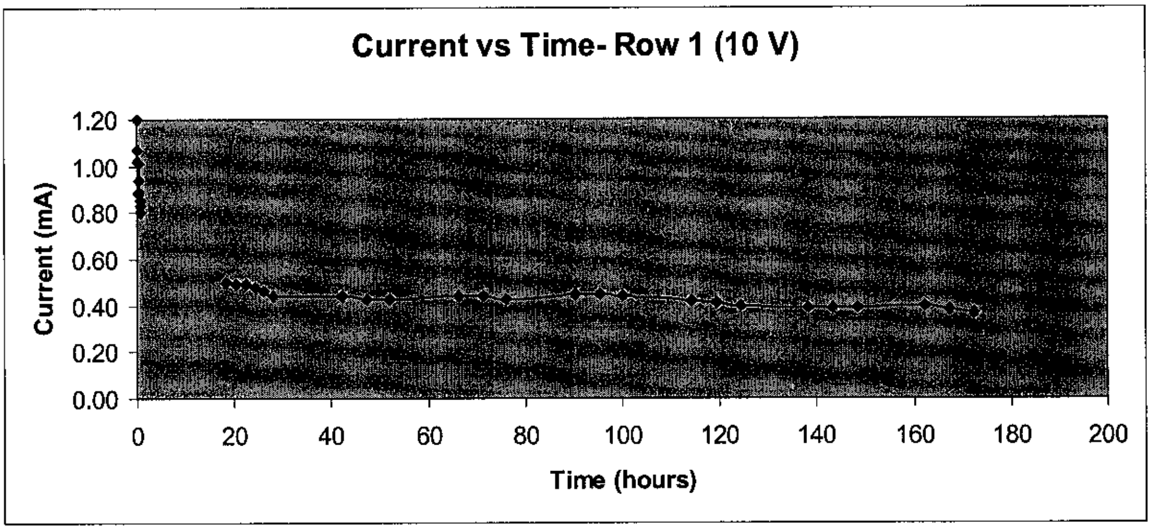


Figure 4.70: Detail Out of current for 10V (Row 1)

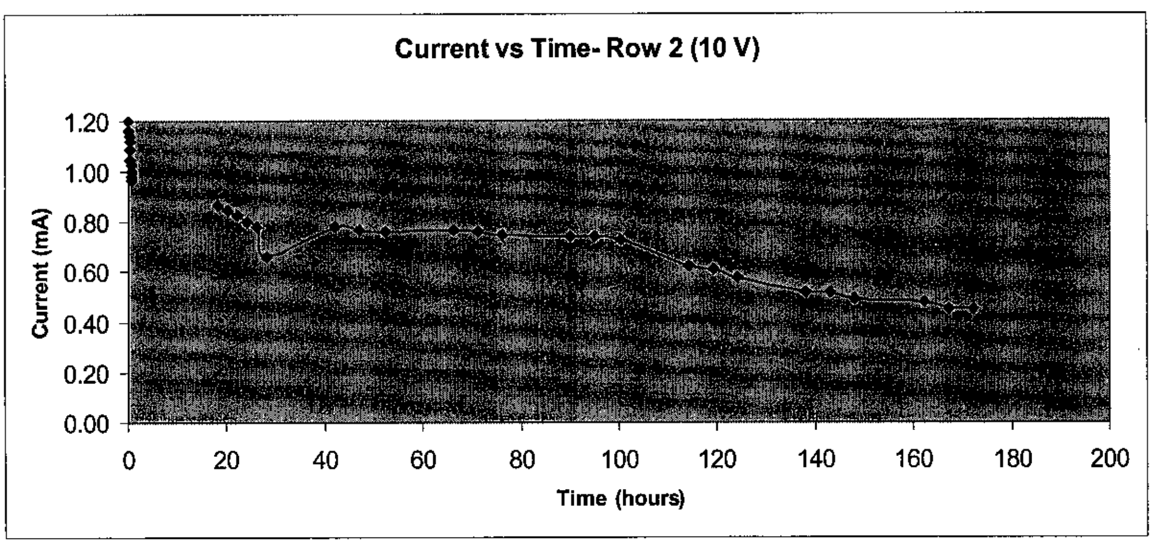


Figure 4.71: Detail Out of current for 10V (Row 2)

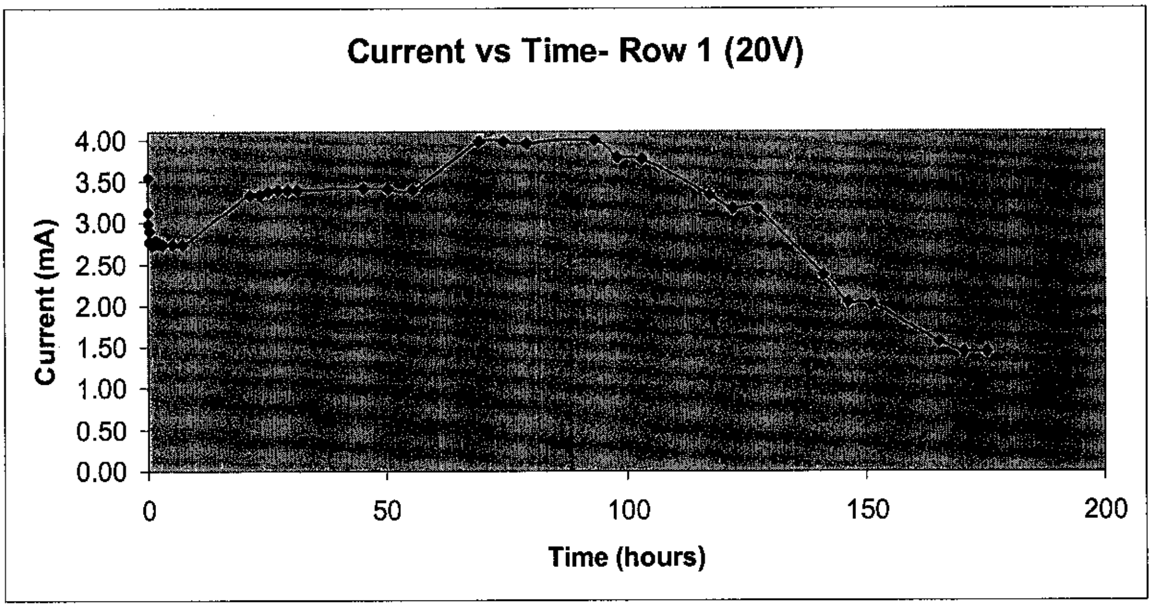


Figure 4.72: Detail Out of current for 20V (Row 1)

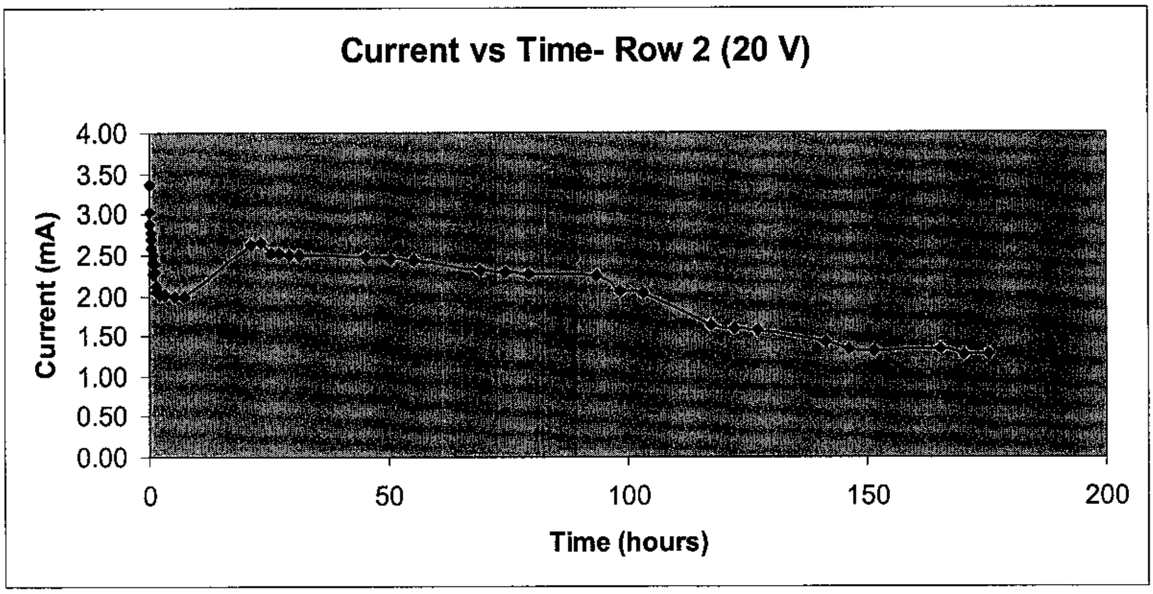


Figure 4.73: Detail Out of current for 20V (Row 2)

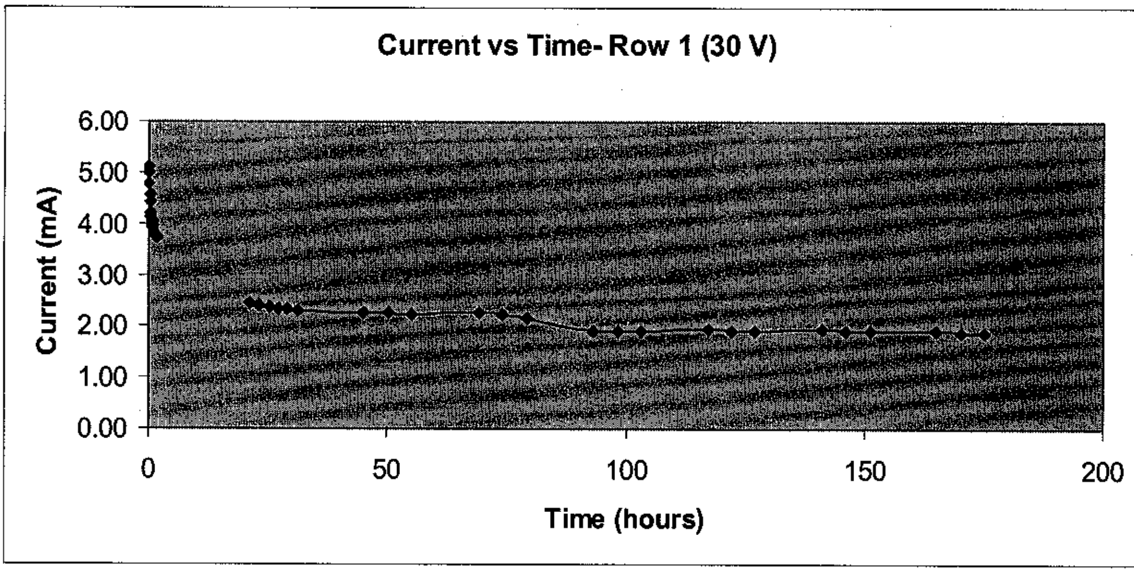


Figure 4.74: Detail Out of current for 30V (Row 1)

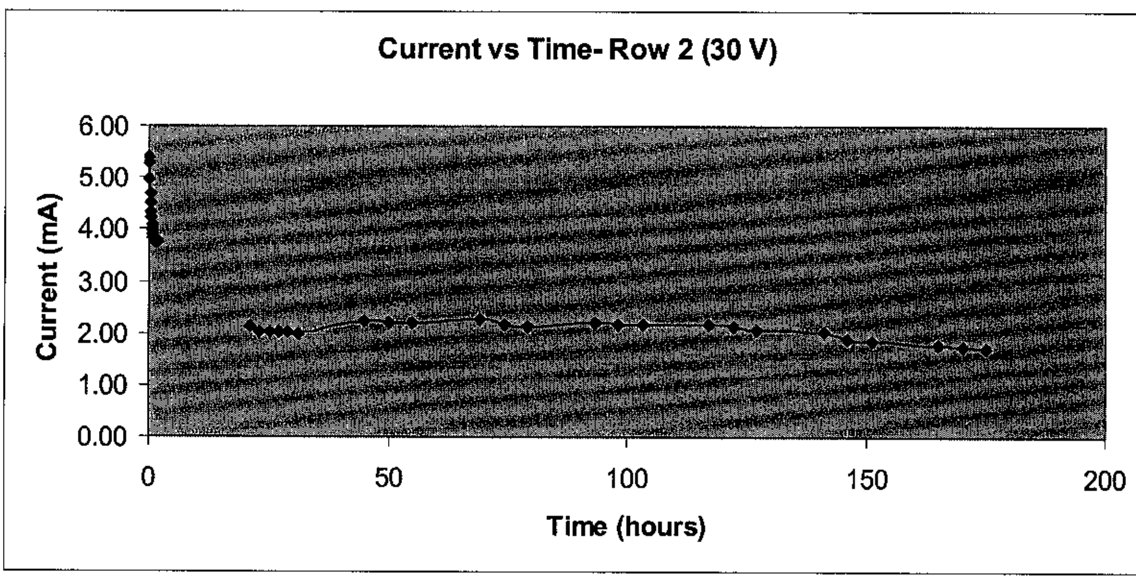


Figure 4.75: Detail Out of current for 30V (Row 2)

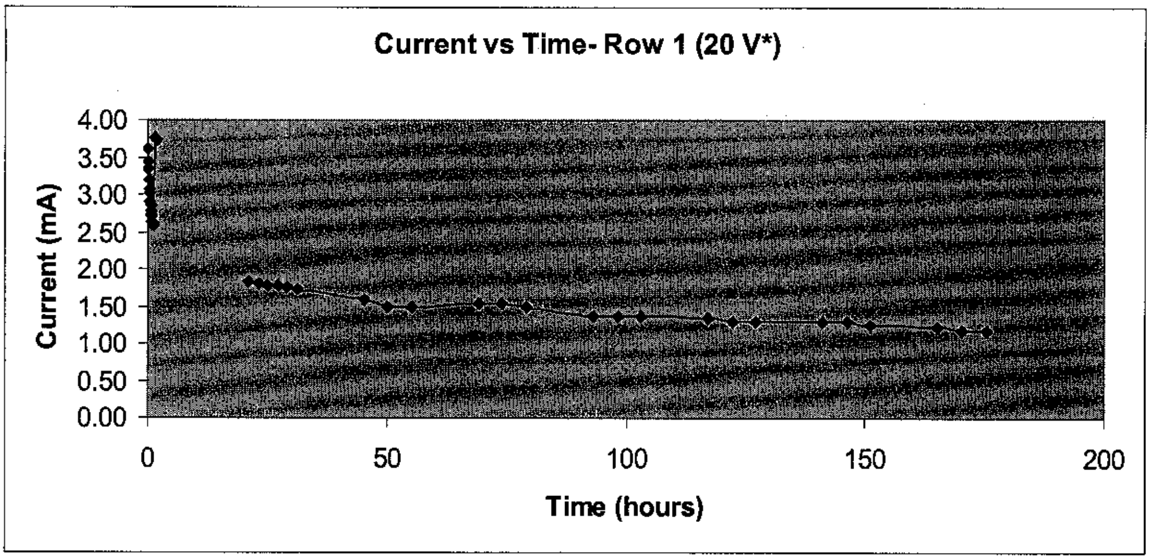


Figure 4.76: Detail Out of current for 20V of Different arrangement (Row 1)

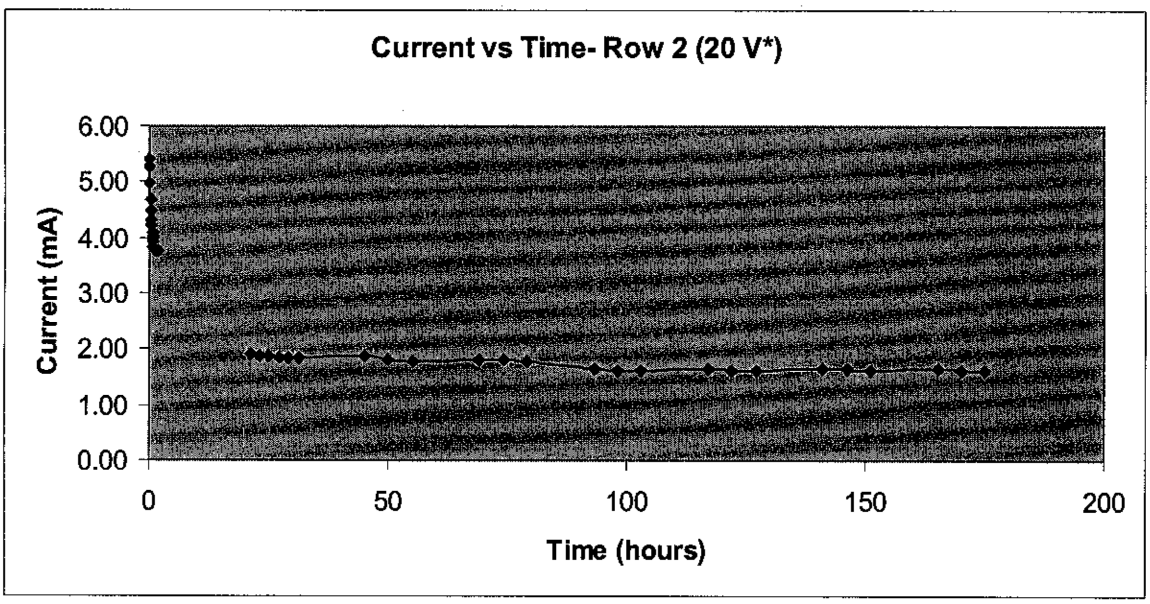


Figure 4.77: Detail Out of current for 20V of Different arrangement (Row 2)

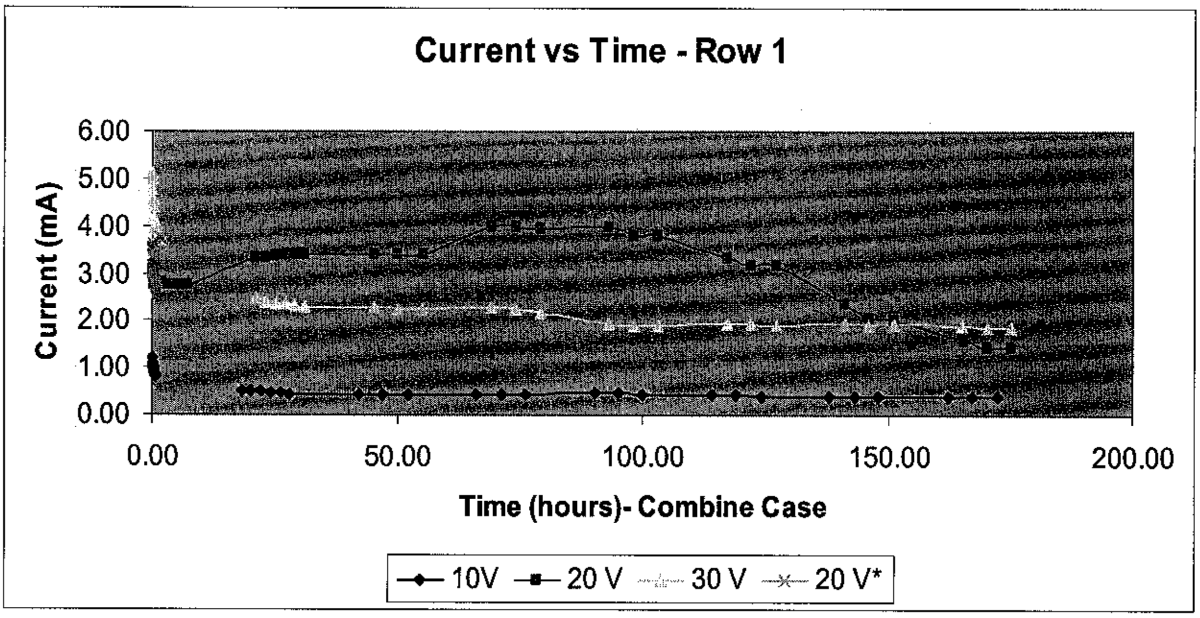


Figure 4.78: Detail Out of combination of current for varies in Voltages (Row 1)

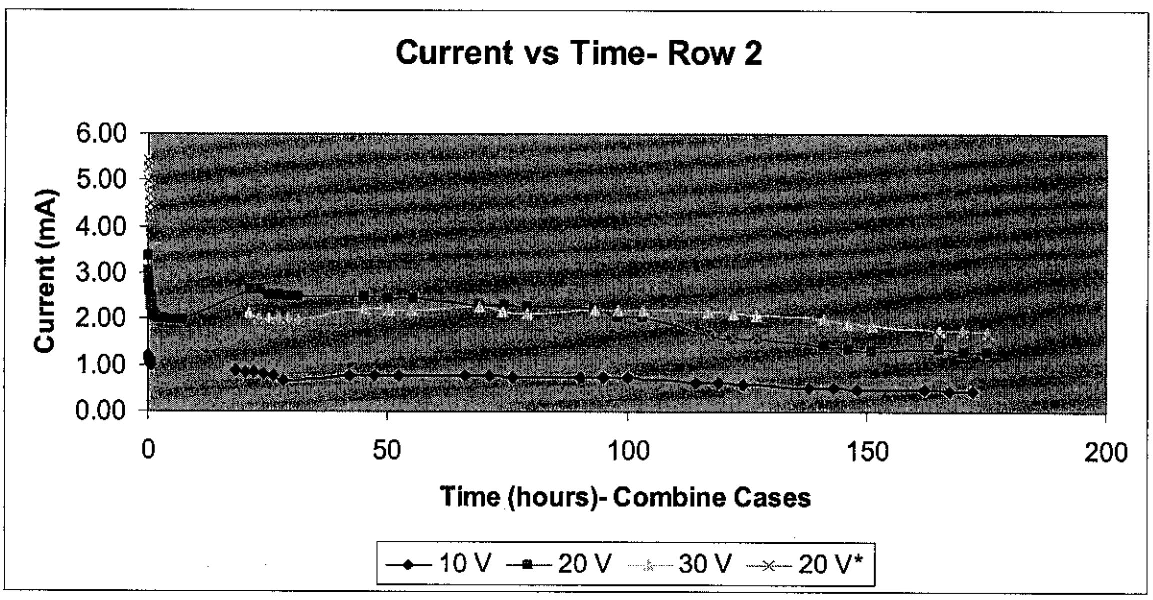


Figure 4.79: Detail Out of combination of current for varies in Voltages (Row 2)

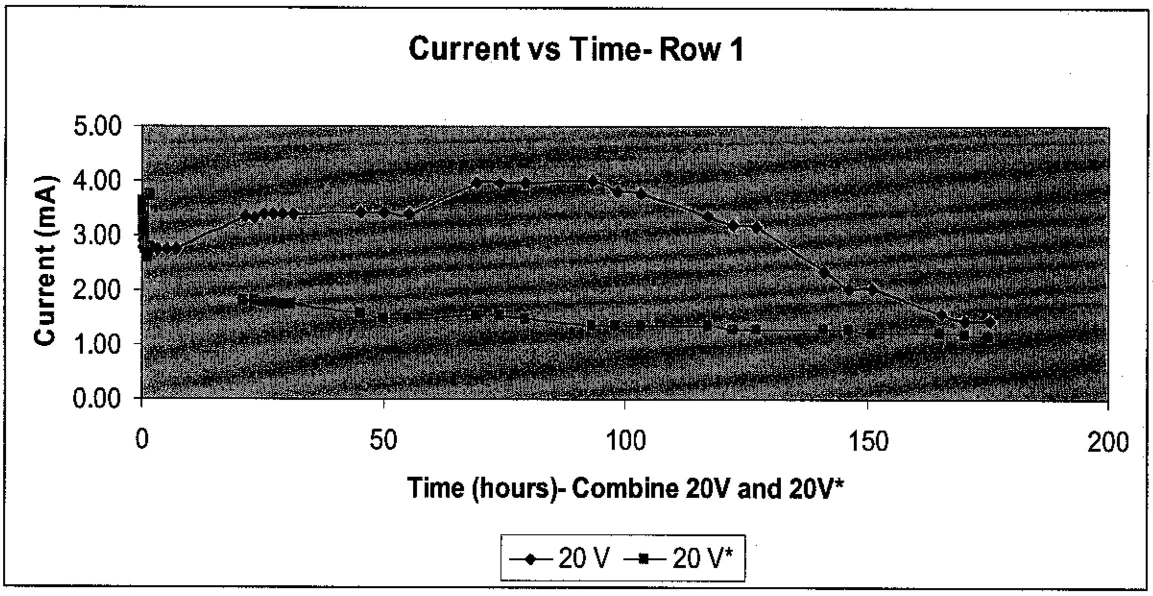


Figure 4.80: Detail Out combination of 20V (Row 1)

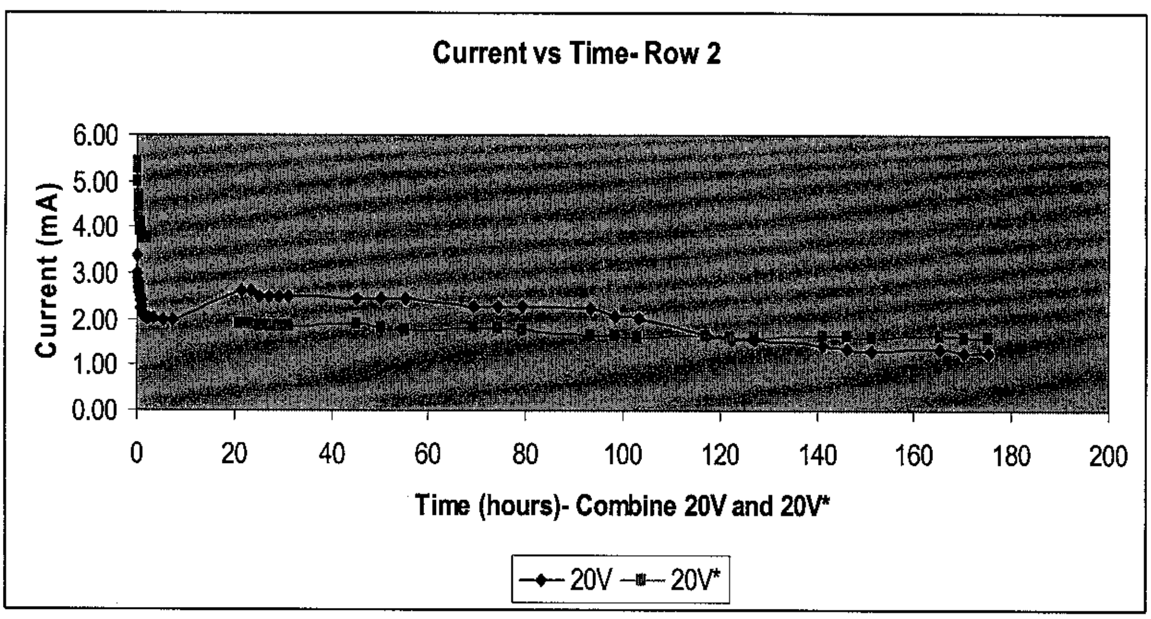


Figure 4.81: Detail Out combination of 20V (Row 2)

APPENDIX 4-6

	Time	Row 1	Row 2
0	0.00	1.20	1.20
5	0.08	1.07	1.16
10	0.17	1.02	1.14
15	0.25	1.01	1.12
20	0.33	0.94	1.09
25	0.42	0.89	1.05
30	0.50	0.88	1.03
35	0.58	0.85	1.00
40	0.67	0.83	0.98
45	0.75	0.80	0.97
50	[illegible]	[illegible]	[illegible]
55	[illegible]	[illegible]	[illegible]
60	[illegible]	[illegible]	[illegible]
65	[illegible]	[illegible]	[illegible]
70	[illegible]	[illegible]	[illegible]
85	[illegible]	[illegible]	[illegible]
100	[illegible]	[illegible]	[illegible]
115	[illegible]	[illegible]	[illegible]
130	[illegible]	[illegible]	[illegible]
190	[illegible]	[illegible]	[illegible]
250	[illegible]	[illegible]	[illegible]
1090	18.17	0.50	0.87
1210	20.17	0.49	0.85
1330	22.17	0.49	0.83
1450	24.17	0.48	0.80
1570	26.17	0.46	0.78
1690	28.17	0.44	0.66
2530	42.17	0.44	0.78
2830	47.17	0.43	0.77
3130	52.17	0.43	0.76
3970	66.17	0.44	0.77
4270	71.17	0.44	0.76
4570	76.17	0.43	0.75
5410	90.17	0.45	0.74
5710	95.17	0.45	0.74
6010	100.17	0.44	0.73
6850	114.17	0.42	0.62
7150	119.17	0.41	0.61
7450	124.17	0.4	0.58
8290	138.17	0.39	0.52
8590	143.17	0.39	0.52
8890	148.17	0.39	0.49
9730	162.17	0.4	0.48
10030	167.17	0.38	0.48
10330	172.17	0.37	0.45

DAY 1 (30/3/2005)

	Time	Row 1	Row 2
0	1815	1.20	1.20
5	1820	1.07	1.16
10	1825	1.02	1.14
15	1830	1.01	1.12
20	1835	0.94	1.09
25	1840	0.89	1.05
30	1845	0.88	1.03
35	1850	0.85	1.00
40	1855	0.83	0.98
45	1900	0.80	0.97
50	1905	[illegible]	[illegible]
55	1910	[illegible]	[illegible]
60	1915	[illegible]	[illegible]
65	1930	[illegible]	[illegible]
70	1945	[illegible]	[illegible]
85	2000	[illegible]	[illegible]
100	2015	[illegible]	[illegible]
115	2030	[illegible]	[illegible]
130	2130	[illegible]	[illegible]
190	2230	[illegible]	[illegible]
250	2330	[illegible]	[illegible]

DAY 2 (31/03/2005)

	Time	Row 1	Row 2
1090	0900	0.50	0.87
1210	1100	0.49	0.85
1330	1300	0.49	0.83
1450	1500	0.48	0.80
1570	1700	0.46	0.78
1690	1900	0.44	0.66

DAY 3 (1/04/2005)

	Time	Row 1	Row 2
2530	0900	0.44	0.78
2830	1400	0.43	0.77
3130	1900	0.43	0.76

DAY 4 (2/04/2005)

	Time	Row 1	Row 2
3970	0900	0.44	0.77
4270	1400	0.44	0.76
4570	1900	0.43	0.75

DAY 5 (3/04/2005)

	Time	Row 1	Row 2
5410	0900	0.45	0.74
5710	1400	0.45	0.74
6010	1900	0.44	0.73

DAY 6 (4/04/2005)

	Time	Row 1	Row 2
6850	0900	0.42	0.62
7150	1400	0.41	0.61
7450	1900	0.4	0.58

DAY 7 (5/04/2005)

	Time	Row 1	Row 2
8290	0900	0.39	0.52
8590	1400	0.39	0.52
8890	1900	0.39	0.49

DAY 8 (6/04/2005)

	Time	Row 1	Row 2
9730	0900	0.4	0.48
10030	1400	0.38	0.45
10330	1900	0.37	0.45

Table 4.8: Table of Current and Time for Testing Using 10 Volt during 8 Days

APPENDIX 4- 6

	Time	Row 1	Row 2
0	0.00	3.54	3.37
5	0.08	3.14	3.02
10	0.17	2.99	2.87
15	0.25	2.90	2.78
20	0.33	2.79	2.69
25	0.42	2.77	2.68
30	0.50	2.76	2.59
35	0.58	2.77	2.49
40	0.67	2.76	2.40
45	0.75	2.75	2.41
50	0.83	2.75	2.26
55	0.92	2.77	2.28
60	1.00	2.75	2.40
75	1.25	2.79	2.12
90	1.50	2.78	2.06
105	1.75	2.78	2.05
120	2.00	2.77	2.03
135	2.25	2.76	2.02
195	3.25	2.75	2.01
315	5.25	2.74	1.99
435	7.25	2.73	1.99
1275	21.25	3.34	2.62
1395	23.25	3.33	2.64
1515	25.25	3.38	2.51
1635	27.25	3.39	2.51
1755	29.25	3.40	2.50
1875	31.25	3.40	2.49
2715	45.25	3.42	2.47
3015	50.25	3.41	2.45
3315	55.25	3.40	2.44
4155	69.25	3.98	2.3
4455	74.25	3.97	2.29
4755	79.25	3.96	2.27
5595	93.25	3.93	2.25
5895	98.25	3.8	2.06
6195	103.25	3.78	2.04
7035	117.25	3.34	1.63
7335	122.25	3.18	1.58
7635	127.25	3.17	1.56
8475	141.25	2.36	1.42
8775	146.25	2.04	1.34
9075	151.25	2.02	1.31
9915	165.25	1.57	1.34
10215	170.25	1.45	1.27
10515	175.25	1.45	1.27

DAY 1 (21/4/2005)

	Time	Row 1	Row 2
0	1300	3.54	3.67
5	1305	3.14	3.02
10	1310	2.99	2.87
15	1315	2.90	2.78
20	1320	2.79	2.69
25	1325	2.77	2.68
30	1330	2.76	2.59
35	1335	2.77	2.49
40	1340	2.76	2.40
45	1345	2.76	2.41
50	1350	2.75	2.26
55	1355	2.77	2.28
60	1400	2.75	2.40
75	1415	2.79	2.12
90	1430	2.78	2.06
105	1445	2.78	2.05
120	1500	2.77	2.03
135	1600	2.76	2.02
195	1700	2.75	2.01
315	1800	2.74	1.99
435	1900	2.73	1.99

DAY 2 (21/04/2005)

	Time	Row 1	Row 2
1275	0900	3.34	2.62
1395	1100	3.33	2.64
1515	1300	3.38	2.51
1635	1500	3.39	2.51
1755	1700	3.40	2.50
1875	1900	3.40	2.49

DAY 3
(22/04/2005)

	Time	Row 1	Row 2
2715	0900	3.42	2.47
3015	1400	3.41	2.45
3315	1900	3.40	2.44

DAY 4
(23/04/2005)

	Time	Row 1	Row 2
4155	0900	3.98	2.3
4455	1400	3.97	2.29
4755	1900	3.96	2.27

DAY 5
(25/04/2005)

	Time	Row 1	Row 2
5595	0900	3.99	2.25
5895	1400	3.8	2.06
6195	1900	3.78	2.04

DAY 6
(26/04/2005)

	Time	Row 1	Row 2
7035	0900	3.34	1.63
7335	1400	3.18	1.58
7635	1900	3.17	1.56

DAY 7
(27/04/2005)

	Time	Row 1	Row 2
8475	0900	2.36	1.42
8775	1400	2.04	1.34
9075	1900	2.02	1.31

DAY 8
(28/04/2005)

	Time	Row 1	Row 2
9915	0900	1.57	1.34
10215	1400	1.46	1.27
10515	1900	1.46	1.27

Table 4-9: Table of Current and Time for 20 Volt during 8 days

APPENDIX 4-6

	Time	Row 1	Row 2
0	0.00	5.11	5.40
5	0.08	4.98	5.28
10	0.17	4.77	4.97
15	0.25	4.57	4.67
20	0.33	4.42	4.50
25	0.42	4.20	4.32
30	0.50	4.13	4.21
35	0.58	4.07	4.09
40	0.67	4.04	4.02
45	0.75	3.95	3.98
50	0.83	3.96	3.91
55	0.92	3.92	3.83
60	1.00	3.78	3.8
70	1.17	3.77	3.78
85	1.42	3.75	3.77
100	1.67	3.74	3.76
115	1.92	3.72	3.75
130	2.17	[illegible]	[illegible]
190	3.17	[illegible]	[illegible]
310	5.17	[illegible]	[illegible]
430	7.17	[illegible]	[illegible]
1270	21.17	2.46	2.12
1390	23.17	2.41	2.01
1510	25.17	2.38	2.02
1630	27.17	2.35	2.01
1750	29.17	2.32	2.03
1870	31.17	2.30	1.98
2710	45.17	2.28	2.24
3010	50.17	2.25	2.21
3310	55.17	2.24	2.20
4150	69.17	2.27	2.26
4450	74.17	2.23	2.17
4750	79.17	2.16	2.14
5590	93.17	1.92	2.20
5890	98.17	1.90	2.18
6190	103.17	1.90	2.18
7030	117.17	1.93	2.15
7330	122.17	1.92	2.12
7630	127.17	1.90	2.07
8470	141.17	1.94	2.01
8770	146.17	1.91	1.89
9070	151.17	1.92	1.86
9910	165.17	1.89	1.76
10210	170.17	1.87	1.74
10510	175.17	1.86	1.72

DAY 1 (14/4/2005)

	Time	Row 1	Row 2
0	1730	5.11	5.40
5	1735	4.98	5.28
10	1740	4.77	4.97
15	1745	4.57	4.67
20	1750	4.42	4.50
25	1755	4.20	4.32
30	1800	4.13	4.21
35	1805	4.07	4.09
40	1810	4.04	4.02
45	1815	3.95	3.98
50	1820	3.96	3.91
55	1825	3.92	3.83
60	1830	3.78	3.8
70	1845	3.77	3.78
85	1900	3.75	3.77
100	1915	3.74	3.76
115	1930	3.72	3.75
130	[illegible]	[illegible]	[illegible]
190	[illegible]	[illegible]	[illegible]
310	[illegible]	[illegible]	[illegible]
430	[illegible]	[illegible]	[illegible]

DAY 2 (15/04/2005)

	Time	Row 1	Row 2
1270	0900	2.46	2.12
1390	1100	2.41	2.01
1510	1300	2.38	2.02
1630	1500	2.35	2.01
1750	1700	2.32	2.03
1870	1900	2.30	1.98

DAY 3
(16/04/2005)

	Time	Row 1	Row 2
2710	0900	2.28	2.24
3010	1400	2.25	2.21
3310	1900	2.24	2.20

DAY 6
(19/04/2005)

	Time	Row 1	Row 2
7030	0900	1.93	2.15
7330	1400	1.92	2.12
7630	1900	1.90	2.07

DAY 4
(17/04/2005)

	Time	Row 1	Row 2
4150	0900	2.27	2.26
4450	1400	2.23	2.17
4750	1900	2.15	2.14

DAY 7
(20/04/2005)

	Time	Row 1	Row 2
8470	0900	1.94	2.01
8770	1400	1.91	1.89
9070	1900	1.92	1.86

DAY 5
(18/04/2005)

	Time	Row 1	Row 2
5590	0900	1.92	2.20
5890	1400	1.90	2.18
6190	1900	1.90	2.18

DAY
8(21/04/2005)

	Time	Row 1	Row 2
9910	0900	1.89	1.76
10210	1400	1.87	1.74
10510	1900	1.86	1.72

Table 4.10: Table of Current and Time for 30 Volt during 8 days

APPENDIX 4-7

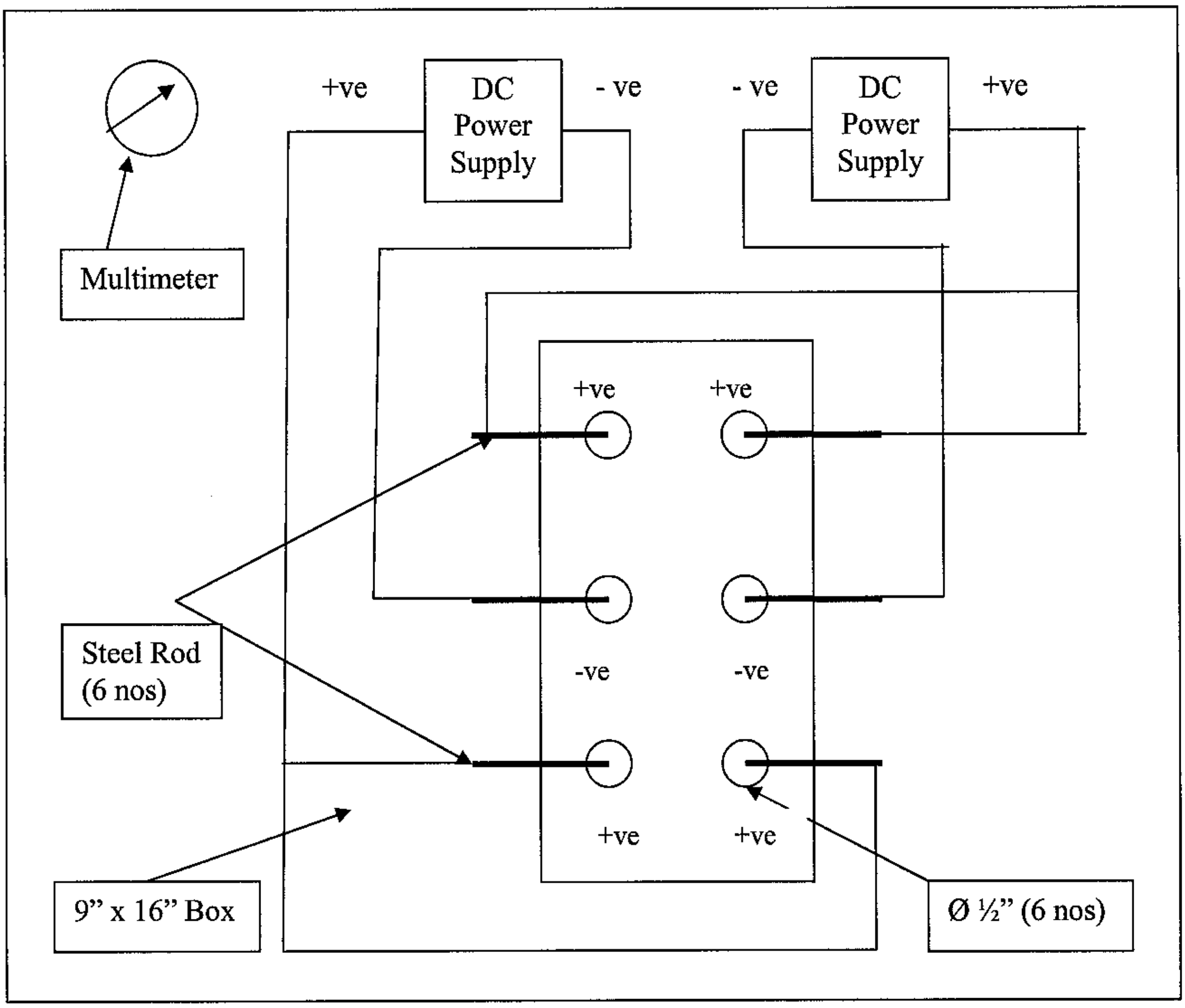


Figure 4.48: Different arrangement of the cathodes and anodes for 20 volt

APPENDIX 4-7

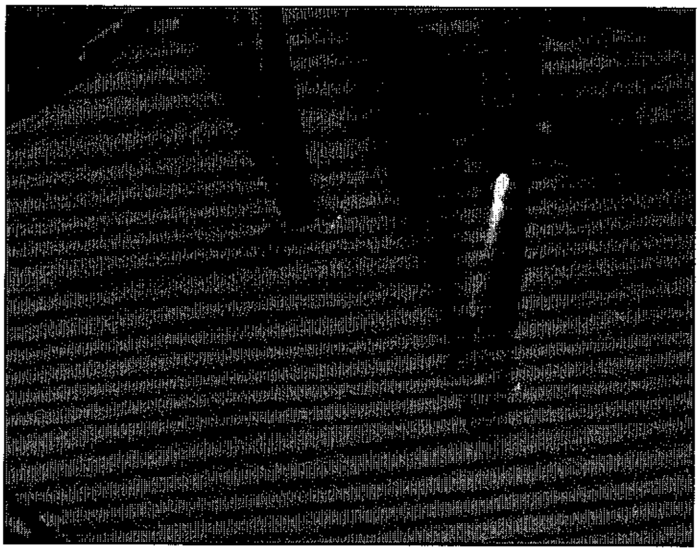


Figure 4.54: Ponding Phenomenon at the cathodes (I)

Figure 4.55: Ponding Phenomenon at the cathodes (II)

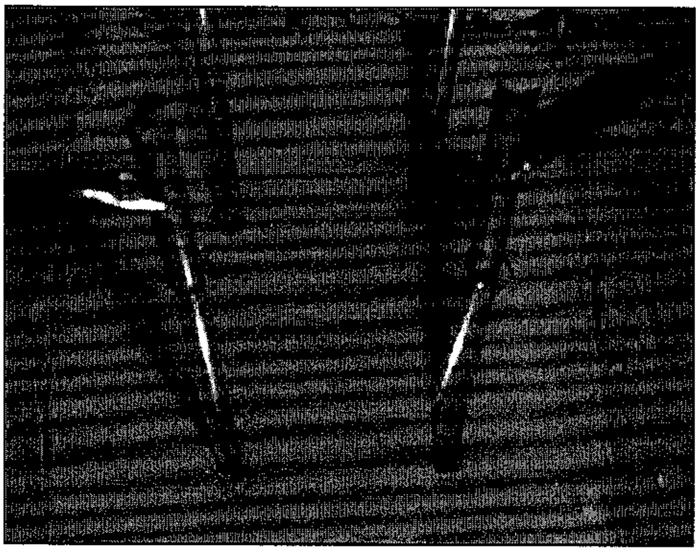


Figure 4.56: Ponding Phenomenon at the cathodes (III)

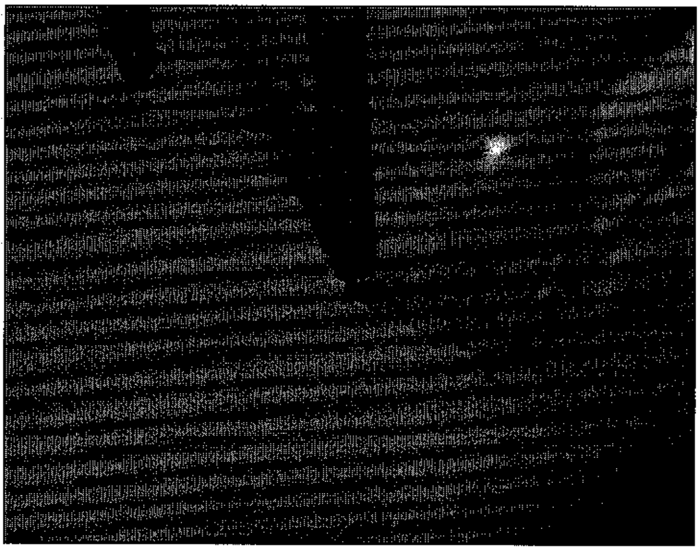


Figure 4.57: Ponding Phenomenon at the cathodes (IV)

APPENDIX 4-8

TEST 2 : 20V (Different orientation of the rod)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	29.17	47.06	41.01	6.05	11.84	51.09
2	29.37	44.4	39.9	4.5	10.53	42.74
3	29.14	42.08	38.19	3.89	9.05	42.98
4	29.27	38.08	35.48	2.6	6.21	41.87
5	37.78	56.62	51.17	5.45	13.39	40.70
					Average	43.87

Container	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	19.7	34.24	30.01	4.23	10.31	41.03
2	19.66	32.32	28.57	3.75	8.91	42.09
3	19.61	31.04	27.79	3.25	8.18	39.73
4	19.53	32.83	29.03	3.8	9.5	40.00
5	19.65	37.67	32.26	5.41	12.61	42.90
					Average	41.15

Container	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	19.44	45.49	37.99	7.5	18.55	40.43
2	19.37	36.08	31.23	4.85	11.86	40.89
3	19.37	35.3	30.85	4.45	11.48	38.76
4	19.5	35.93	31.02	4.91	11.52	42.62
5	19.36	41.86	35.19	6.67	15.83	42.14
					Average	40.97

Table 4.12: Table of Moisture Content for 20 Volt (Different arrangement)

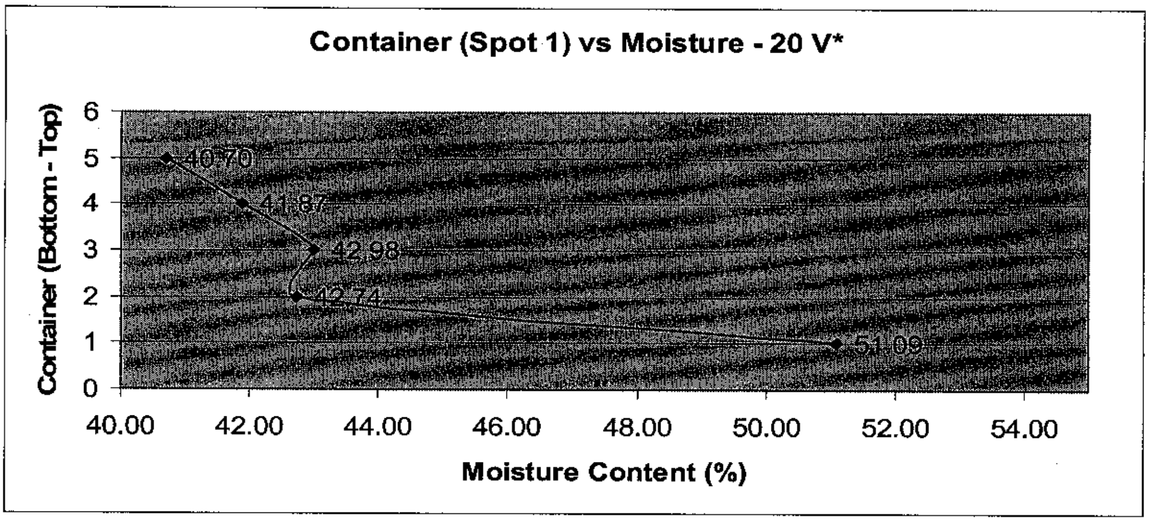


Figure 4.58: Layer of Sample 1 against Moisture for 20V (Different arrangement)

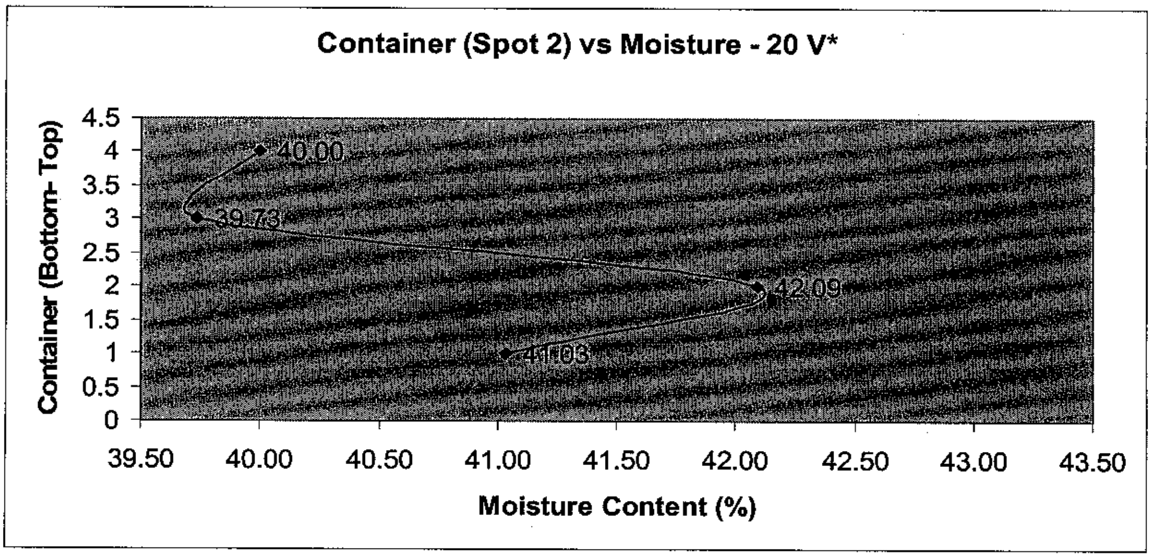


Figure 4.59: Layer of the sample 2 against Moisture for 20V (Different arrangement)

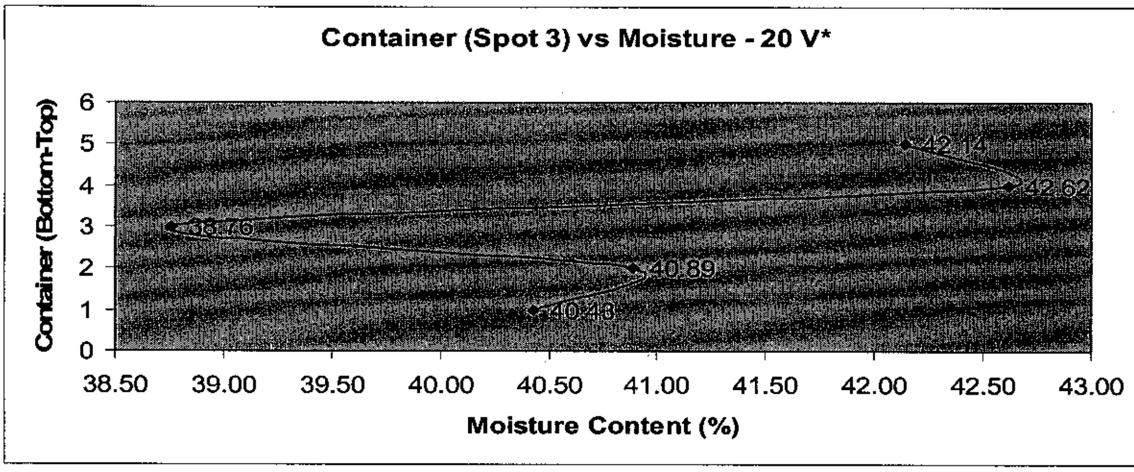


Figure 4.60: Layer of the sample 3 against Moisture for 20V (Different arrangement)

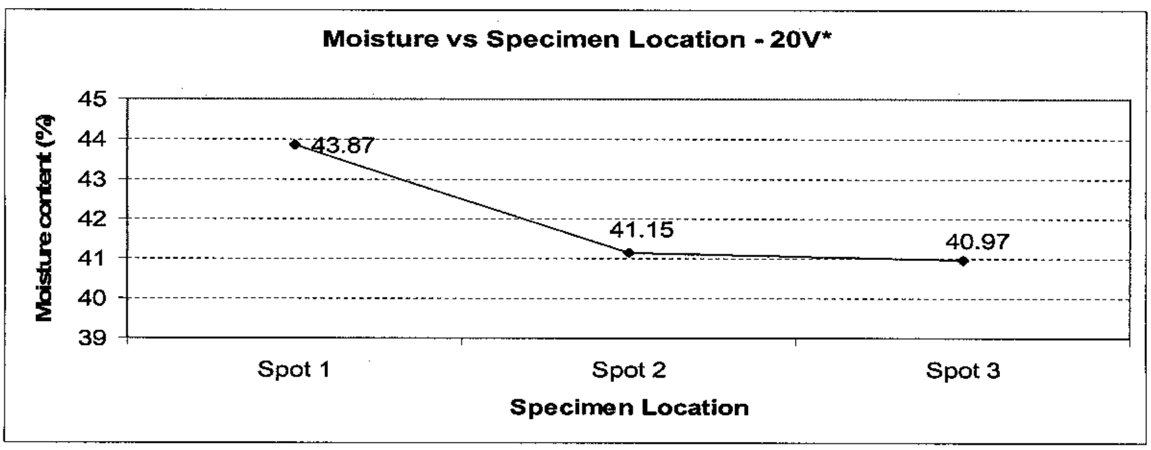


Figure 4.61: Moisture versus Sample Location (Different arrangement)

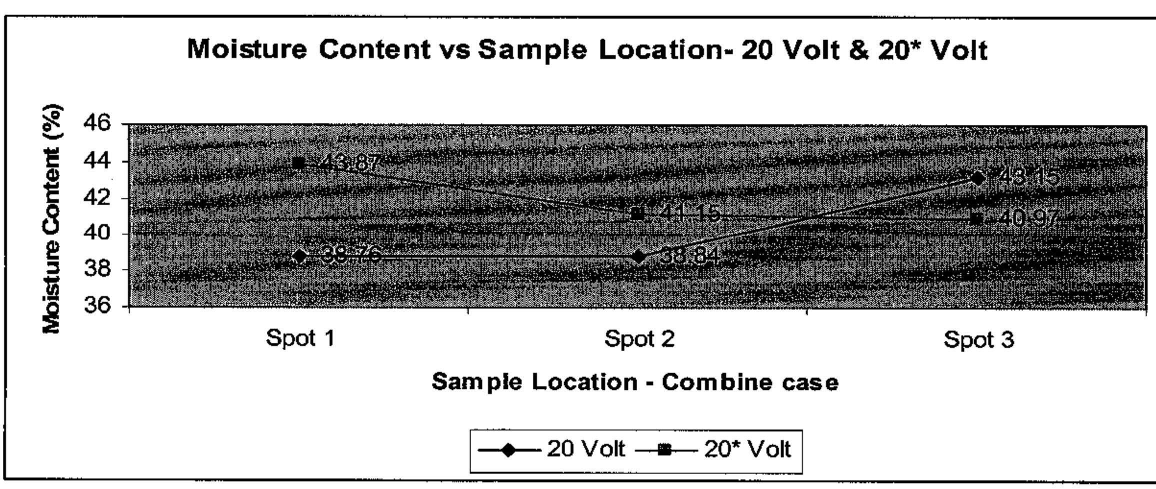


Figure 4.62: Comparison of Moisture Content with different anodes/cathodes arrangement

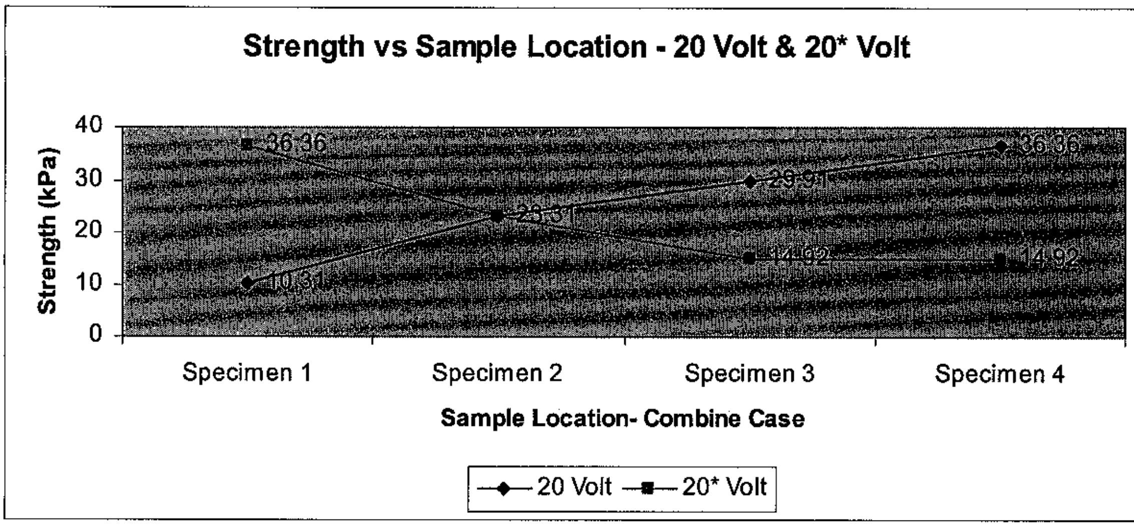


Figure 4.63: Comparison the Strength of soil with different anodes/cathodes arrangement

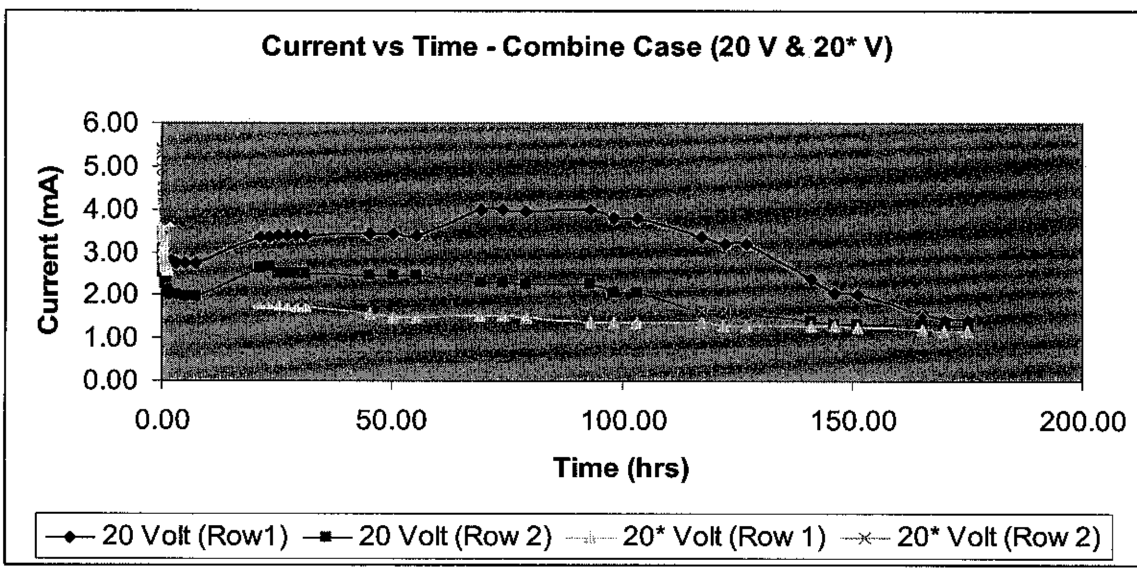


Figure 4.64: Comparison the Current applied to the soil with different anodes/cathodes arrangement

APPENDIX 4-8

	Time	Row 1	Row 2
0	0.00	3.62	5.40
5	0.08	3.44	5.28
10	0.17	3.33	4.97
15	0.25	3.19	4.67
20	0.33	3.07	4.50
25	0.42	3.02	4.32
30	0.50	2.91	4.21
35	0.58	2.85	4.09
40	0.67	2.79	4.02
45	0.75	2.73	3.98
50	0.83	2.70	3.91
55	0.92	2.64	3.88
60	1.00	2.62	3.8
70	1.17	2.59	3.78
85	1.42	3.75	3.77
100	1.67	3.74	3.76
115	1.92	3.72	3.75
130	2.17		
190	3.17		
310	5.17		
430	7.17		
1270	21.17	1.82	1.91
1390	23.17	1.81	1.89
1510	25.17	1.79	1.88
1630	27.17	1.78	1.86
1750	29.17	1.75	1.85
1870	31.17	1.73	1.84
2710	45.17	1.58	1.89
3010	50.17	1.50	1.80
3310	55.17	1.60	1.79
4150	69.17	1.54	1.82
4450	74.17	1.54	1.81
4750	79.17	1.50	1.79
5590	93.17	1.37	1.64
5890	98.17	1.36	1.63
6190	103.17	1.36	1.62
7030	117.17	1.35	1.64
7330	122.17	1.30	1.62
7630	127.17	1.30	1.61
8470	141.17	1.30	1.65
8770	146.17	1.29	1.64
9070	151.17	1.24	1.61
9910	165.17	1.21	1.64
10210	170.17	1.18	1.62
10510	175.17	1.16	1.61

DAY 1 (7/4/2005)

	Time	Row 1	Row 2
0	1625	3.62	5.40
5	1630	3.44	5.28
10	1635	3.33	4.97
15	1640	3.19	4.67
20	1645	3.07	4.50
25	1650	3.02	4.32
30	1655	2.91	4.21
35	1700	2.85	4.09
40	1705	2.79	4.02
45	1710	2.73	3.98
50	1715	2.70	3.91
55	1720	2.64	3.88
60	1725	2.62	3.8
70	1740	2.59	3.78
85	1755	3.75	3.77
100	1810	3.74	3.76
115	1825	3.72	3.75
130	1925		
190			
310			
430			

DAY 2 (8/04/2005)

	Time	Row 1	Row 2
1270	0900	1.82	1.91
1390	1100	1.81	1.89
1510	1300	1.79	1.88
1630	1500	1.78	1.86
1750	1700	1.75	1.85
1870	1900	1.73	1.84

DAY 3 (9/04/2005)

	Time	Row 1	Row 2
2710	0900	1.58	1.89
3010	1400	1.50	1.80
3310	1900	1.50	1.79

DAY 6 (12/04/2005)

Time	Row 1	Row 2
0900	1.35	1.64
1400	1.30	1.62
1900	1.30	1.61

DAY 4 (10/04/2005)

	Time	Row 1	Row 2
4150	0900	1.54	1.82
4450	1400	1.54	1.81
4750	1900	1.50	1.79

DAY 7 (13/04/2005)

Time	Row 1	Row 2
0900	1.30	1.65
1400	1.29	1.64
1900	1.24	1.61

DAY 5 (11/04/2005)

Time	Row 1	Row 2
0900	1.37	1.64
1400	1.36	1.63
1900	1.36	1.62

DAY 8 (14/04/2005)

Time	Row 1	Row 2
0900	1.21	1.64
1400	1.18	1.62
1900	1.16	1.61

Table 4.11: Table of Current and Time for 20 Volt (Different Arrangement)

APPENDIX 4-9

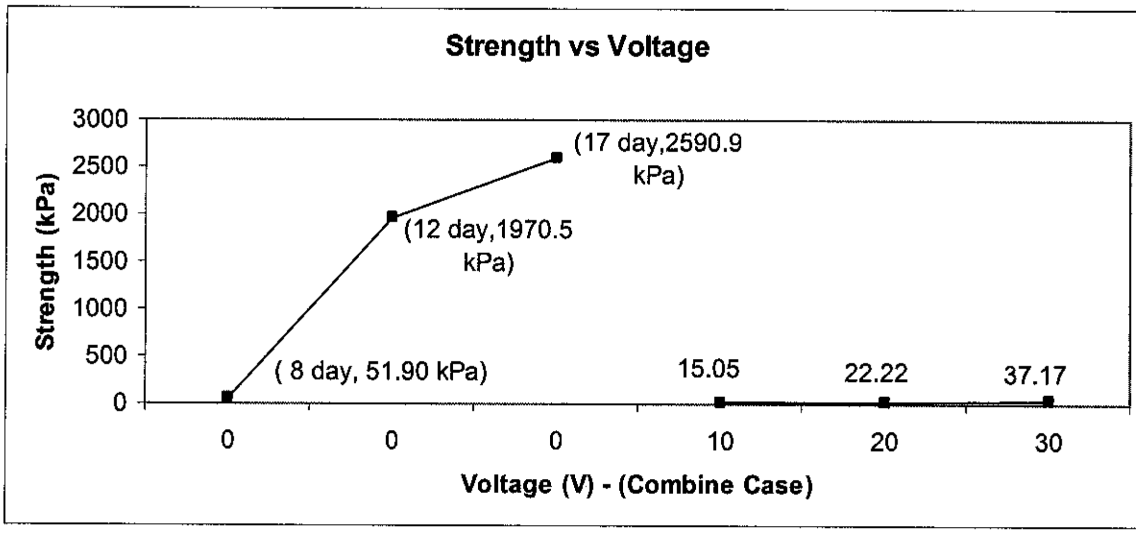


Figure 4.65: Combination of average Strength versus voltage

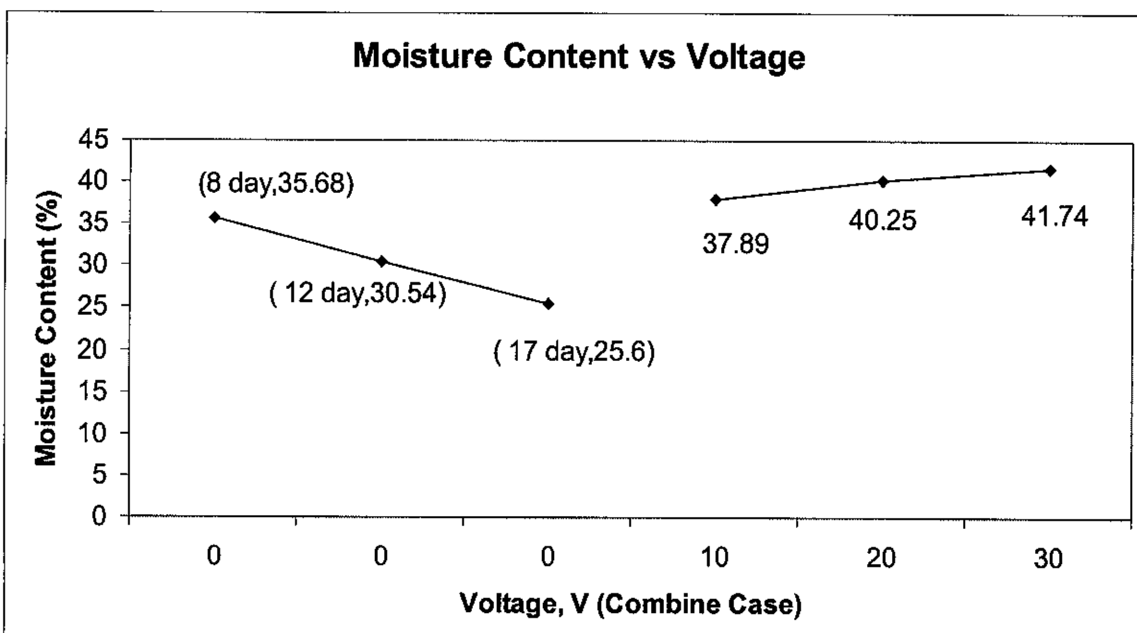


Figure 4.66: Combination of average Moisture Content versus voltage

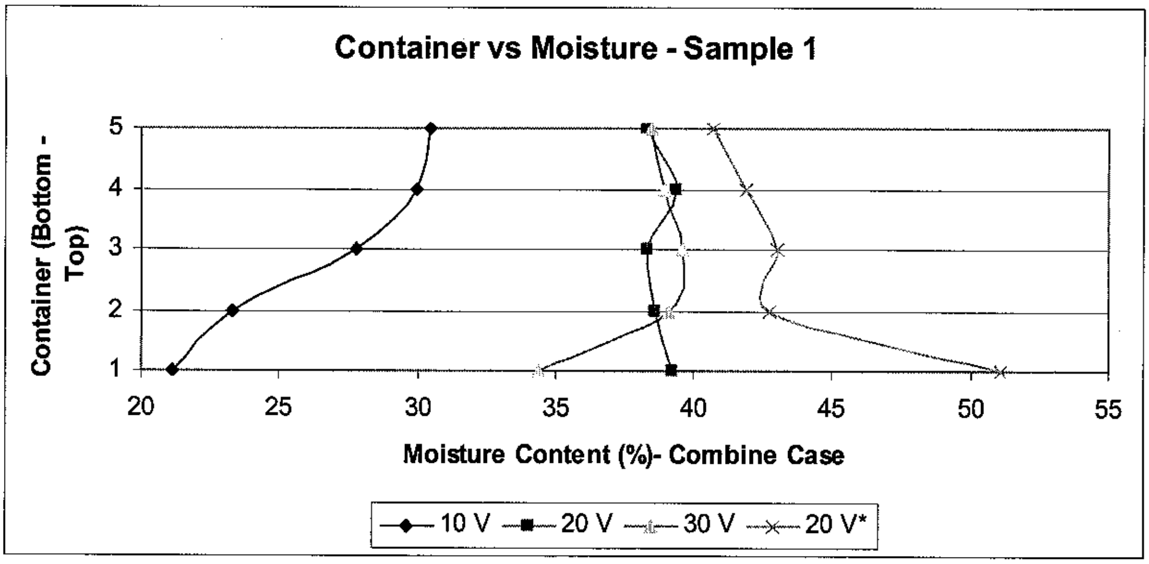


Figure 4.67: Combination of Layers of Sample 1 against Moisture Content

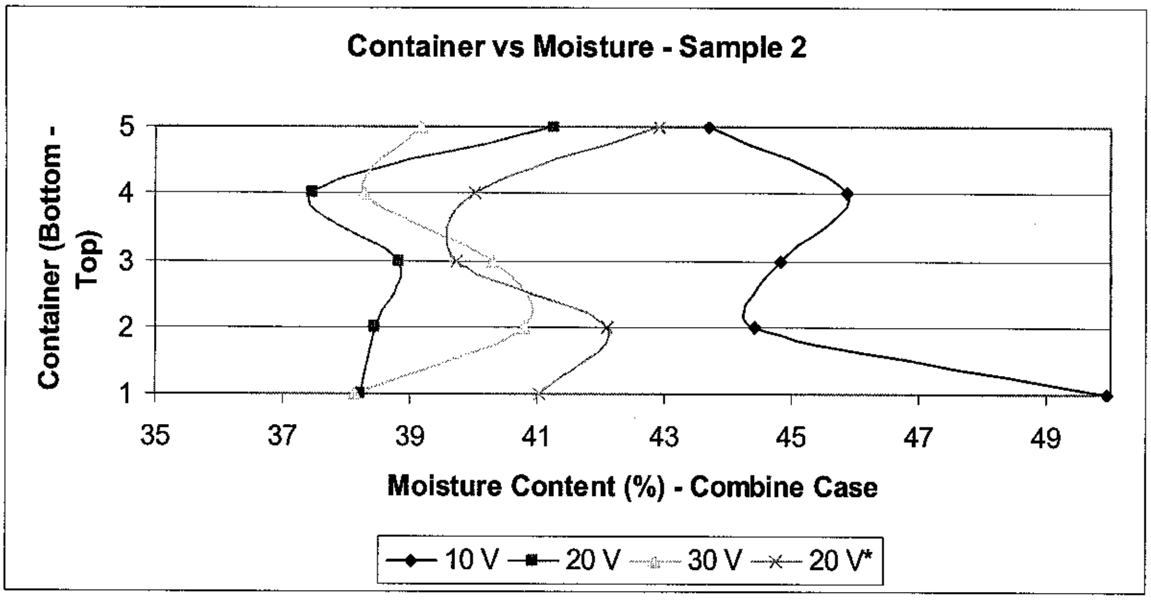


Figure 4.68: Combination of Layers of Sample 2 against Moisture Content

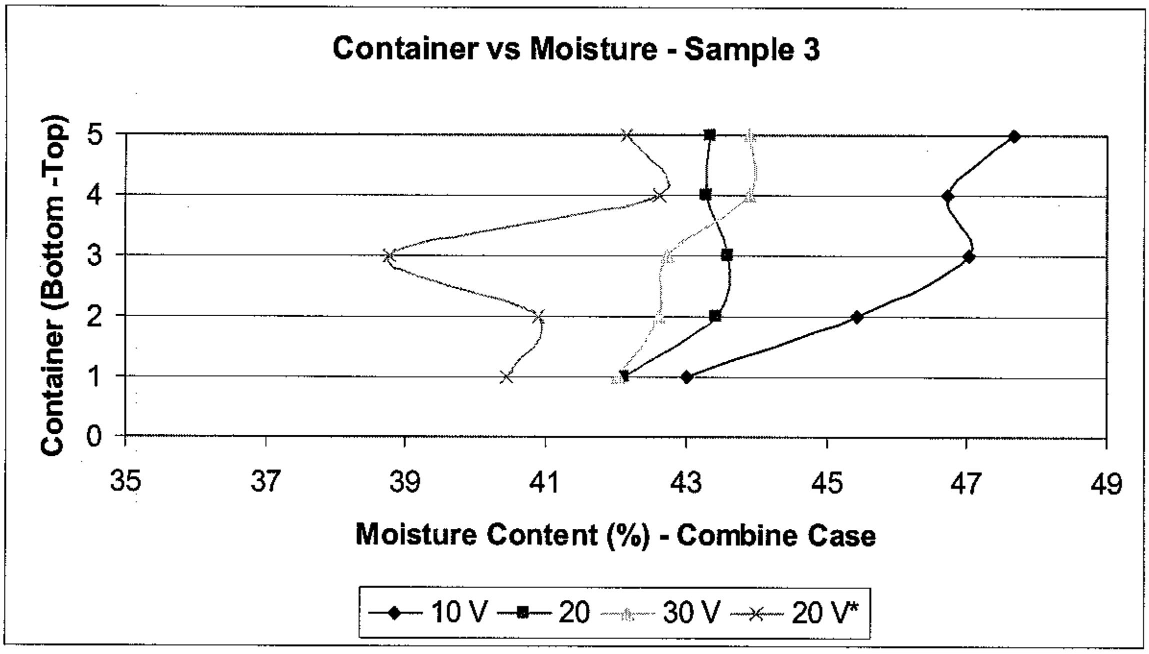
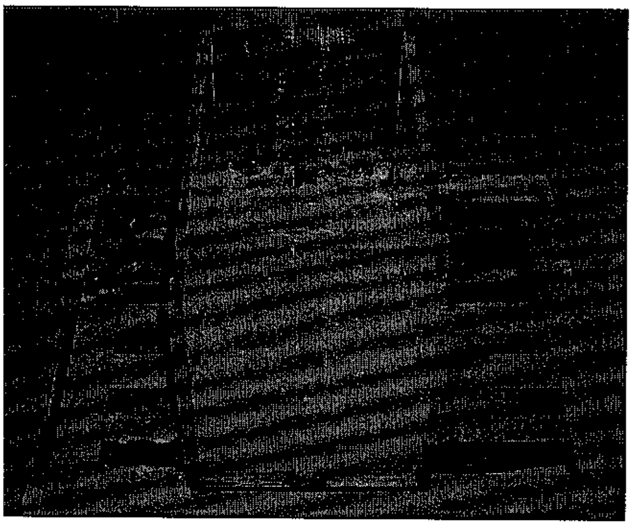
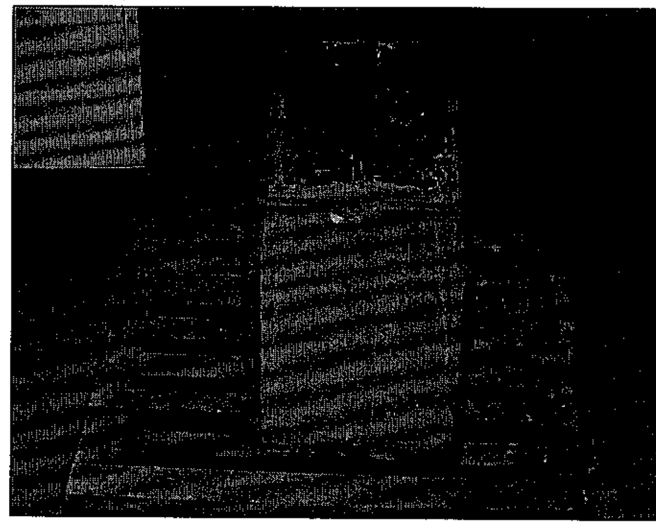
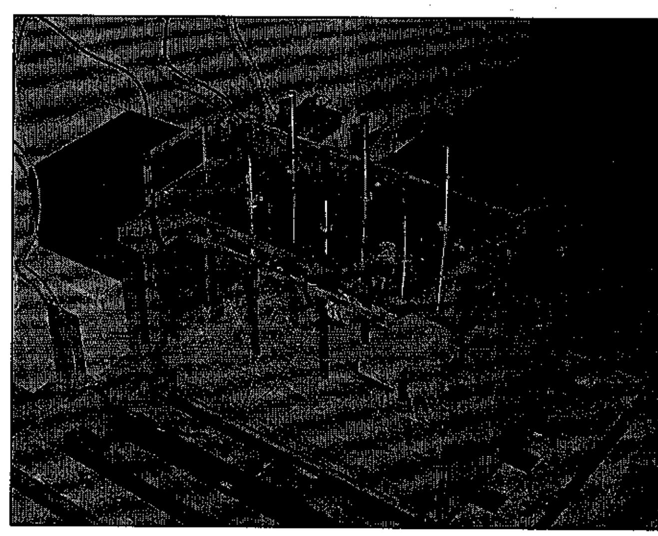
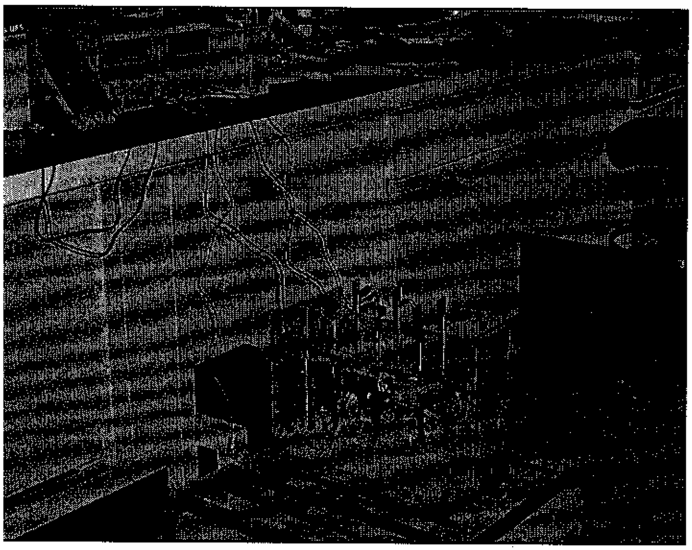


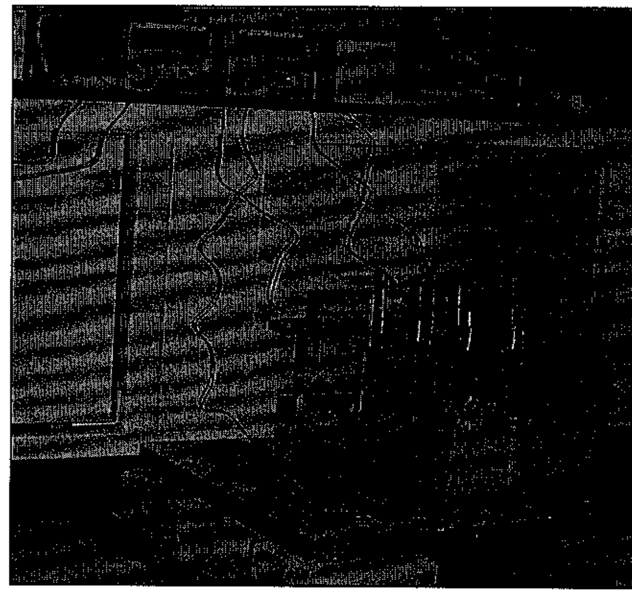
Figure 4.69: Combination of Layers of Sample 3 against Moisture Content

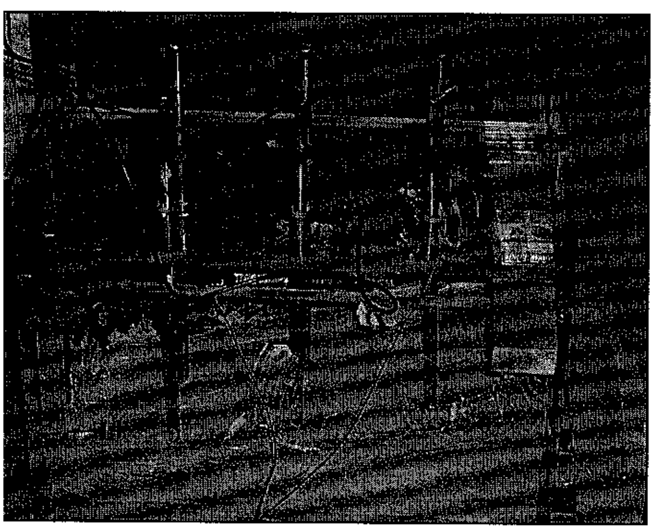
APPENDIX 4-10

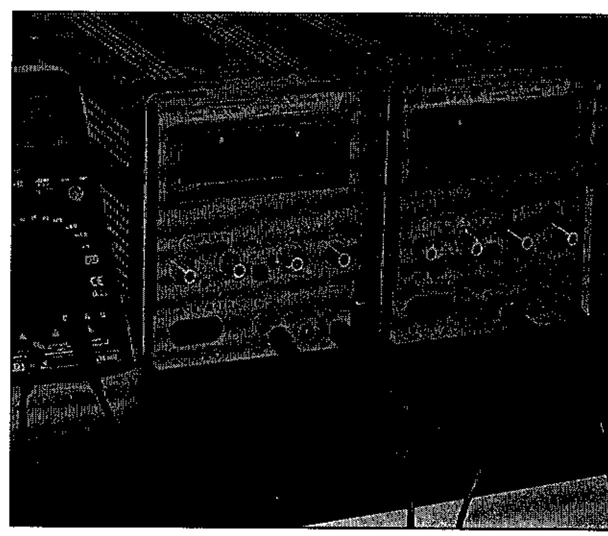



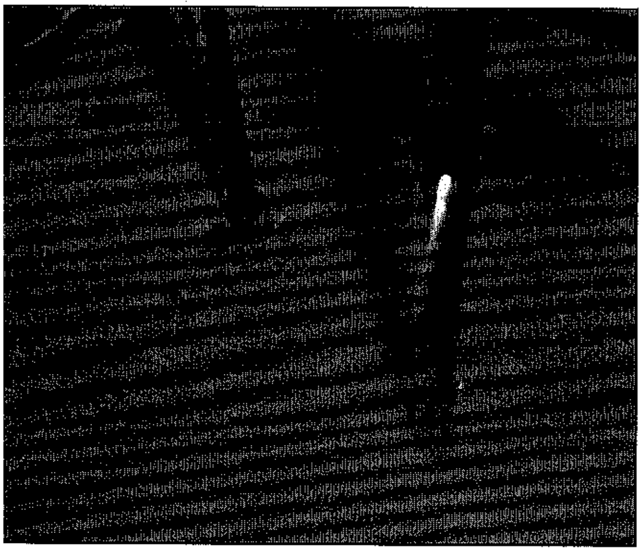


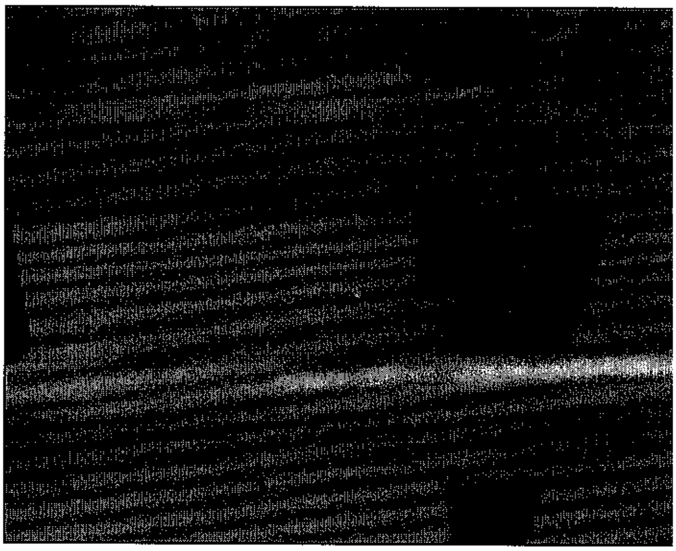


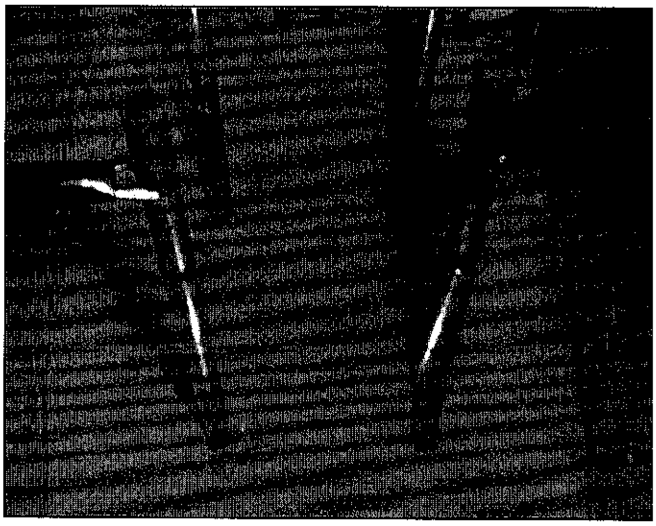












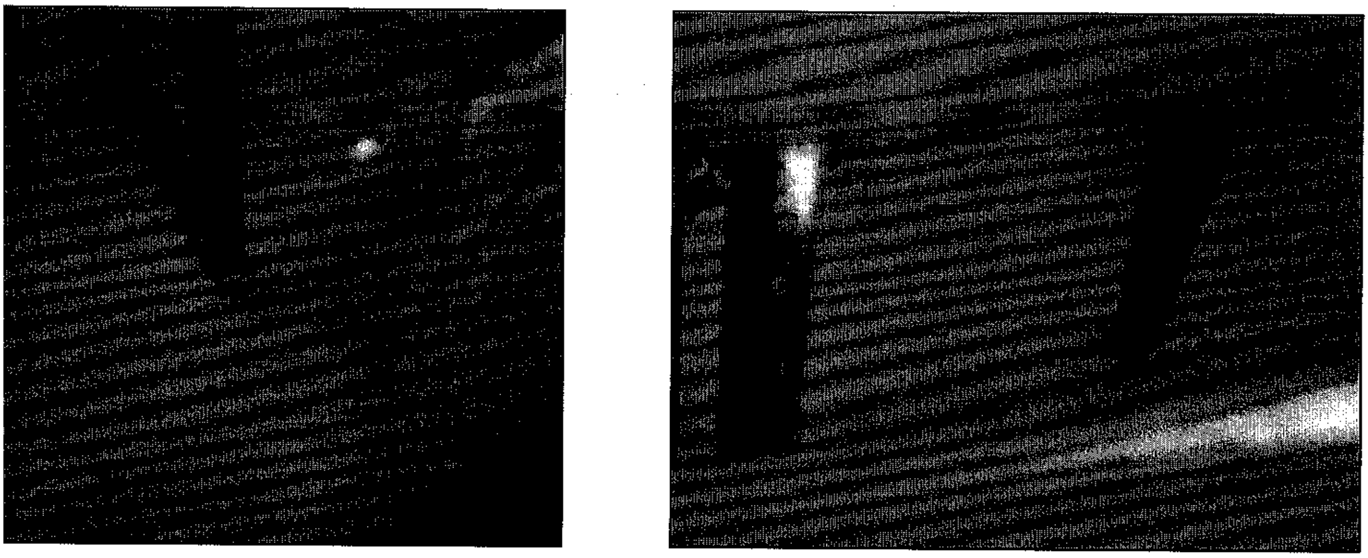
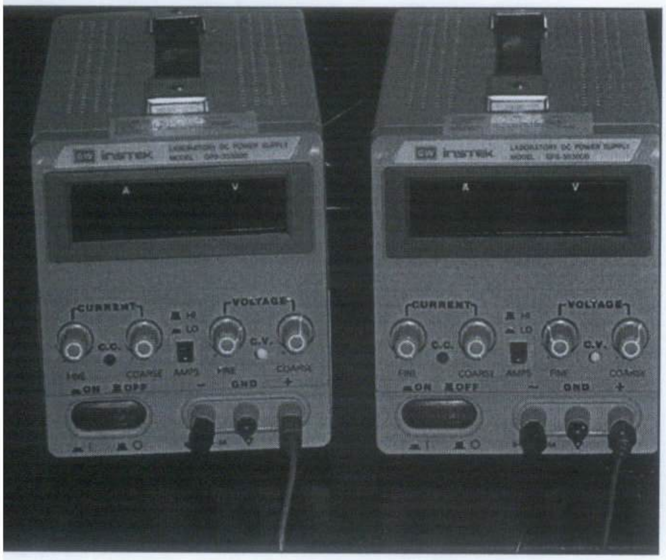
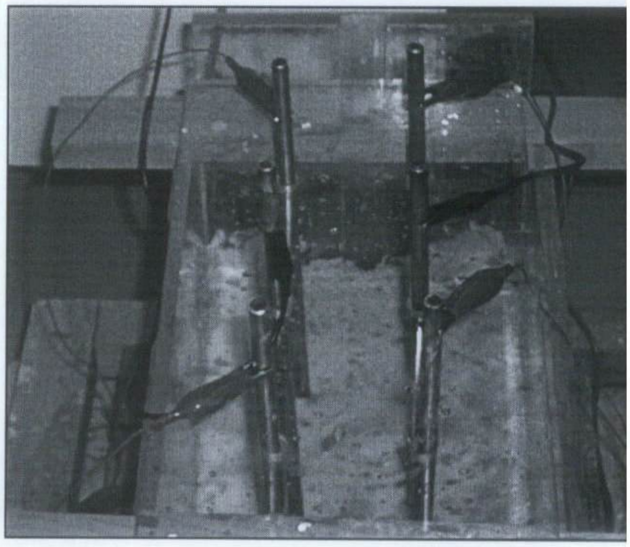


Figure 4.82: Experiment Using 10 Volt

APPENDIX 4-11





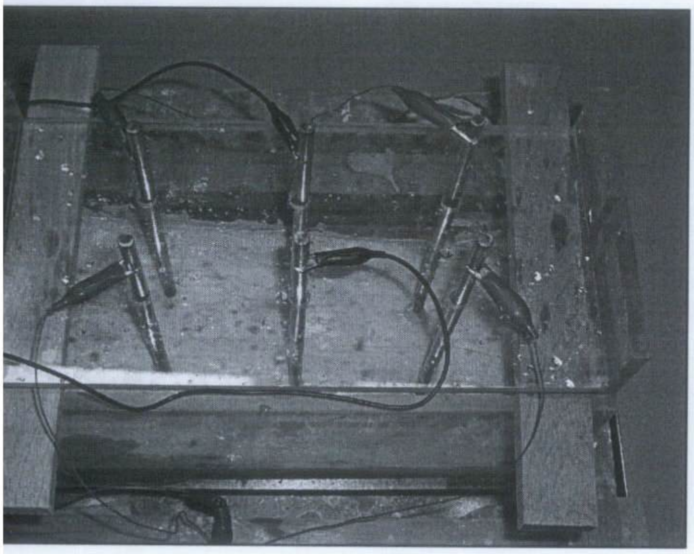
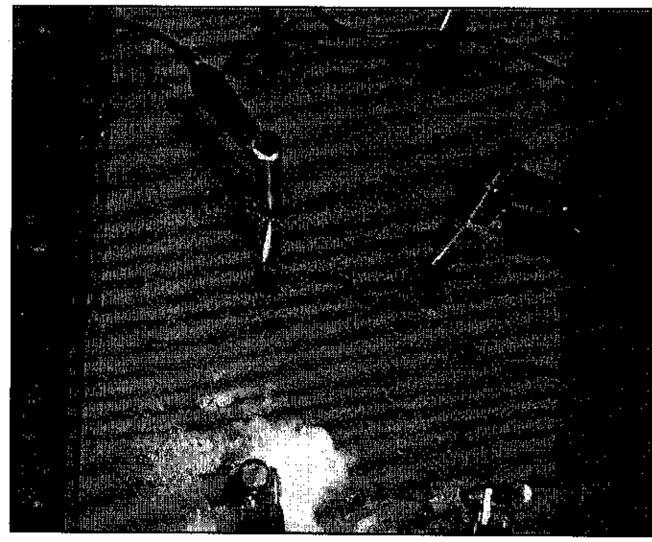
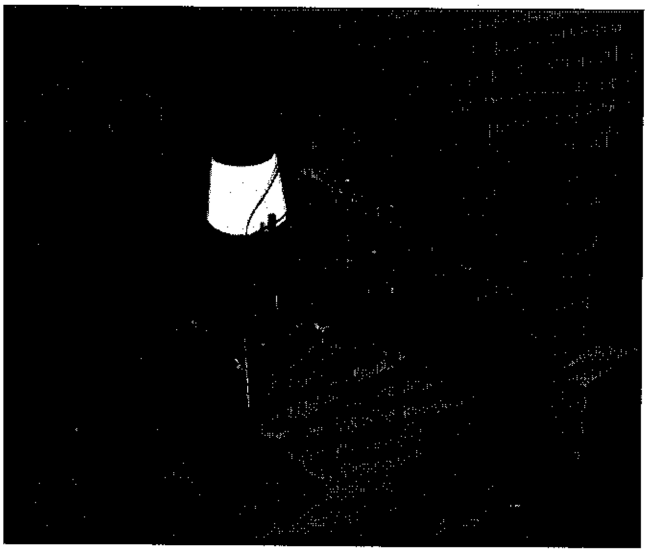
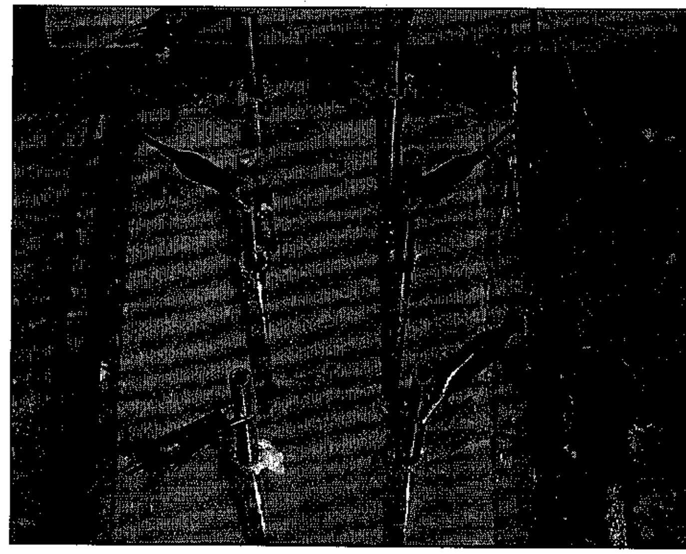


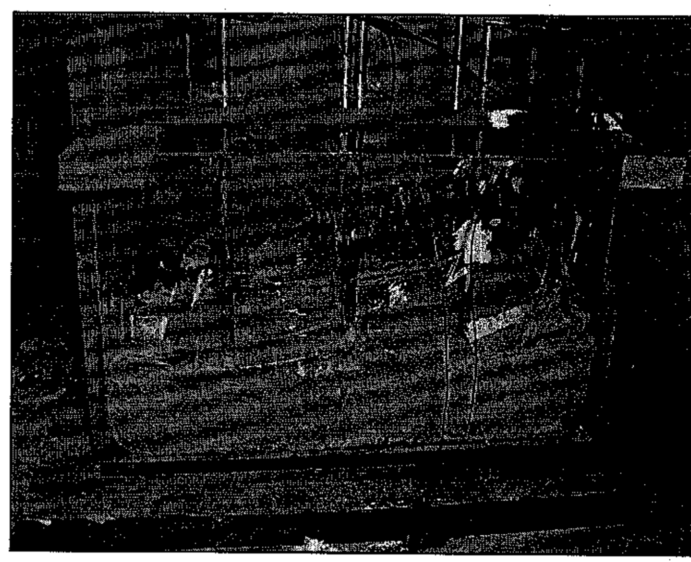
Figure 4.83: Experiment Using 20 Volt

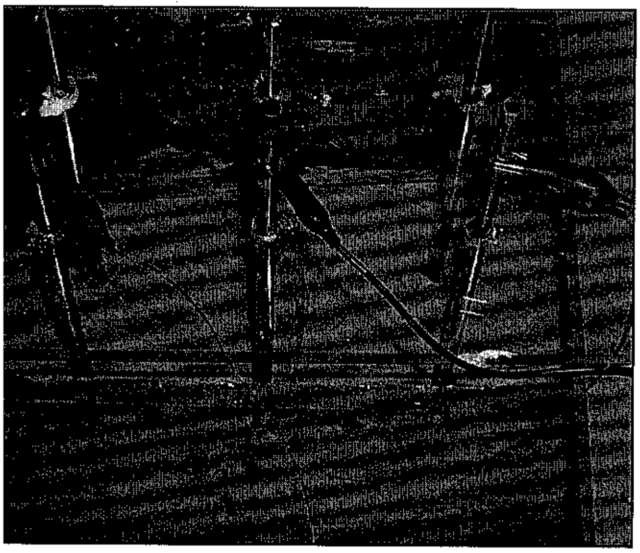
APPENDIX 4-12

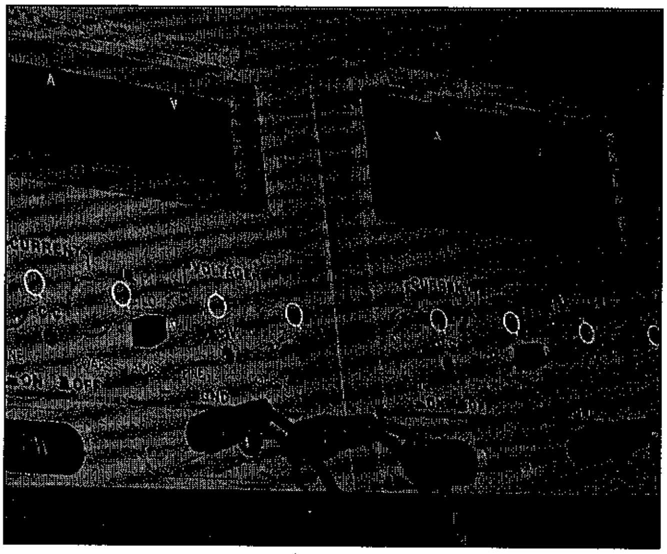


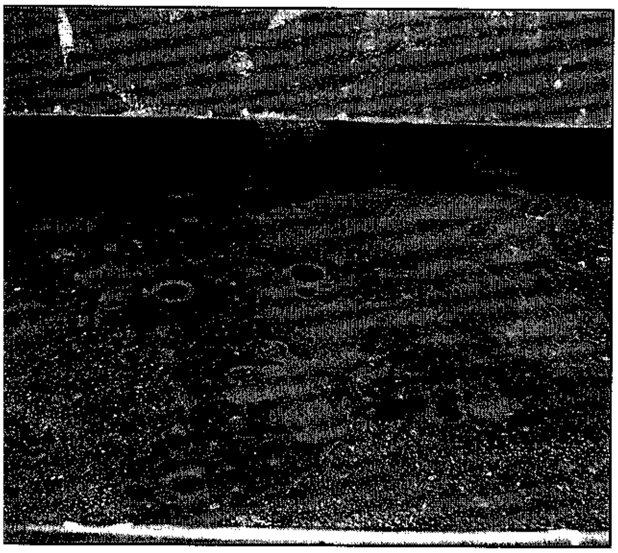


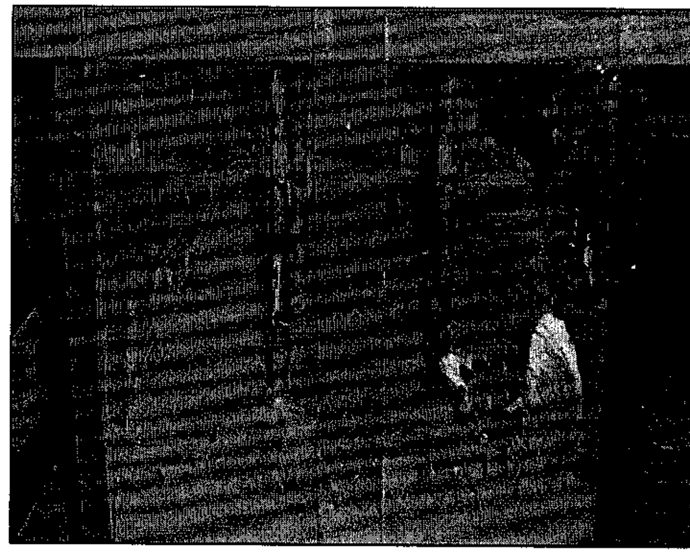


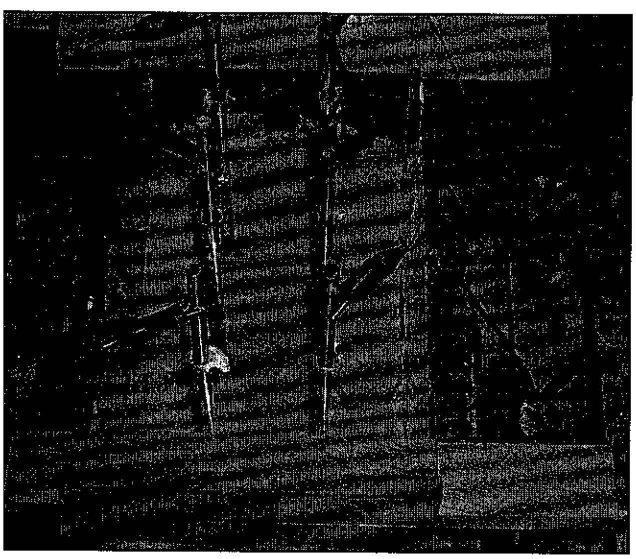


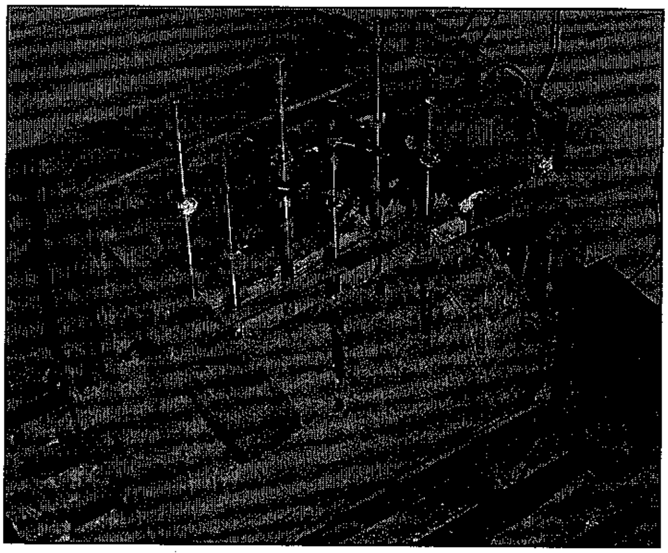










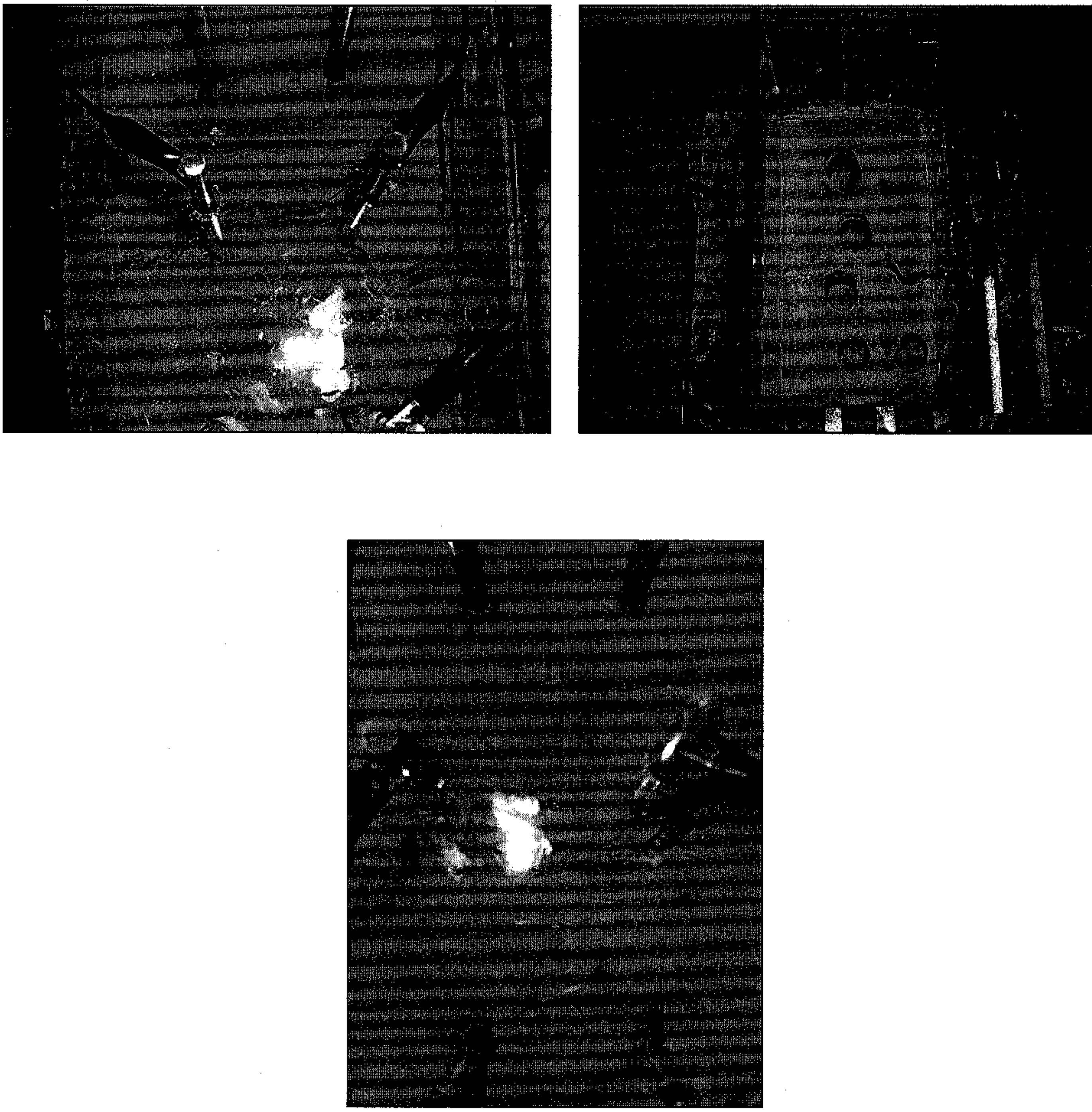


Figure 4.84: Experiment Using 30 Volt